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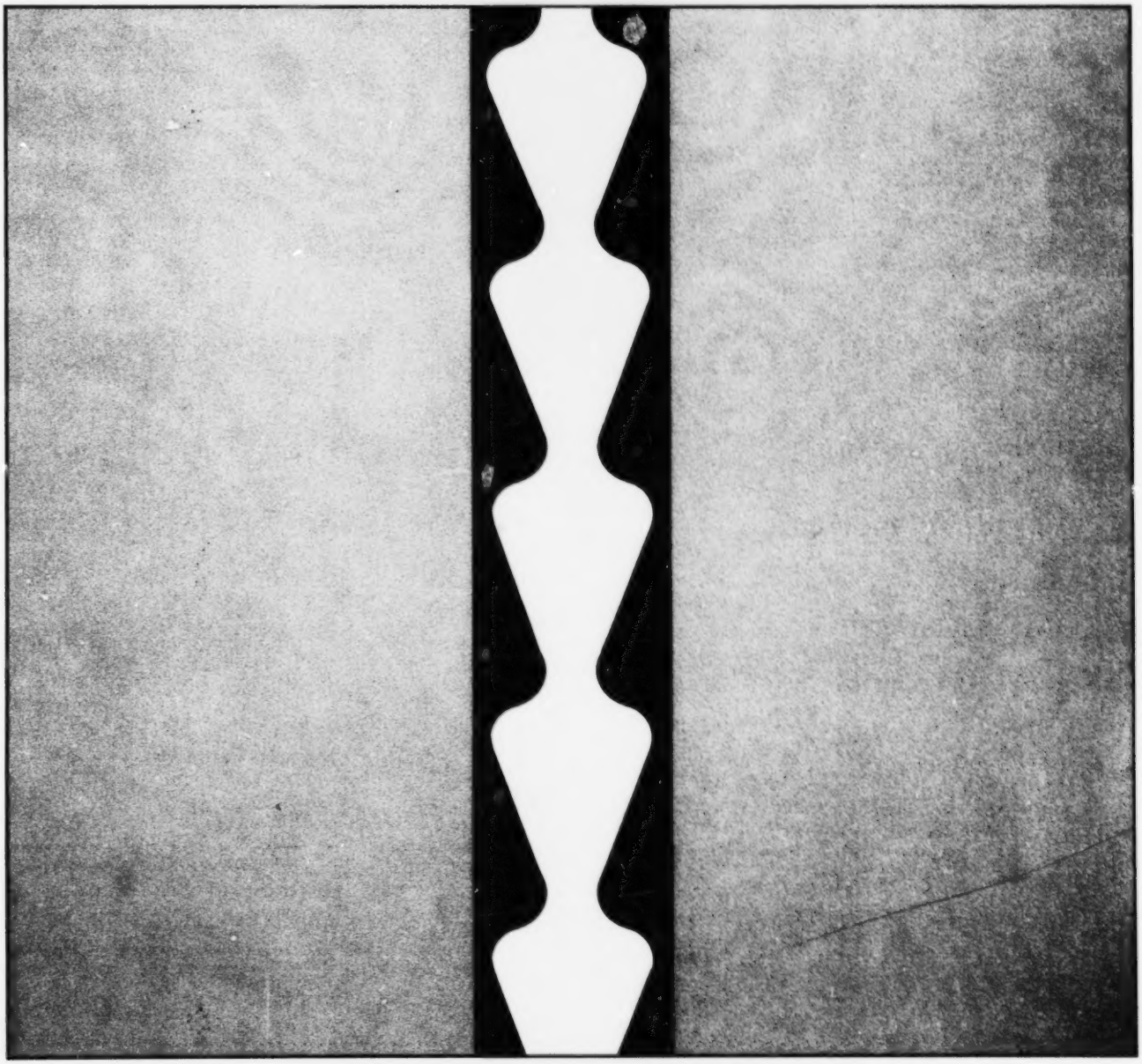
Road and Bridge Deck Drainage Systems
– Part II, Laboratory Investigations



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Road and Bridge Deck Drainage Systems – Part II, Laboratory Investigations

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Abstract:	To complement and extend an earlier study of common sewer and ditch inlets (MTC No. RR228, November 1982), a laboratory study of selected special sewer and ditch inlets was undertaken. Part I of the study dealt with hydraulic characteristics of depressed sewer inlets; inlets operating with either full flow interception, or very large spreads; the ductile iron grate; combination inlets derived from MTC grates DD-713-A and B; the new round frame grate; ditch inlets with flatter grate slopes (6:1); gutter outlets; and inlets installed in setbacks. Part II determines the hydraulic characteristics of the above structures, through laboratory testing of structure prototypes or full-size replicas. The test results, which are presented in this report, are directly usable in road drainage design.
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Road and Bridge Deck Drainage Systems – Part II, Laboratory Investigations

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Testing of the CANRON ductile iron grate was partially sponsored by CANRON Inc., and the test results are incorporated in this report with their permission.

1/ Introduction

During the last seven years, the Ontario Ministry of Transportation and Communications (MTC) sponsored laboratory studies of road and bridge deck drainage. The main objectives of these studies were to establish flow capacities of selected drainage structures under a wide range of operational conditions and, using such data, to develop new drainage design procedures. These objectives were accomplished and the results are presented in an earlier report which dealt with the most common types of drainage structures and operational conditions [3].

In a continuing effort to extend and enhance the earlier research results, the Ministry commissioned the Hydraulics Division of the National Water Research Institute (NWRI) to investigate certain drainage structures and operational conditions which were not studied earlier. The terms of reference for this phase of laboratory investigations may be summarized as follows [4, 5]:

By laboratory testing prototypes or full-size replicas, determine the hydraulic characteristics of depressed inlets, inlets operating with no carry-over flow and large spreads, ductile iron grates, combination inlets, round frame inlets, ditch inlets, gutter outlets and catch basin setbacks.

The recommended scope of the experimental program is given elsewhere [4]. The descriptions of study procedures and results follow.

2/ Experimental Apparatus and Procedures

Hydraulic characteristics of drainage structures can be determined by various methods, among which scale model studies and numerical approximations are particularly common. Both approaches have some inherent limitations. In model studies, it is difficult to achieve hydraulic similitude because of small flow depths and spacings between the grate bars. Analytical approaches require numerous approximations which lead to large uncertainties in the calculated inlet capacity. Consequently, the Ministry requested that inlet capacities be determined through a full-scale laboratory testing. A description of these tests follows.

2.1/ Experimental Apparatus

A special apparatus for testing inlets was built in the Hydraulics Laboratory of the National Water Research Institute. This apparatus, which is shown in Figure 1, comprised the following principal components:

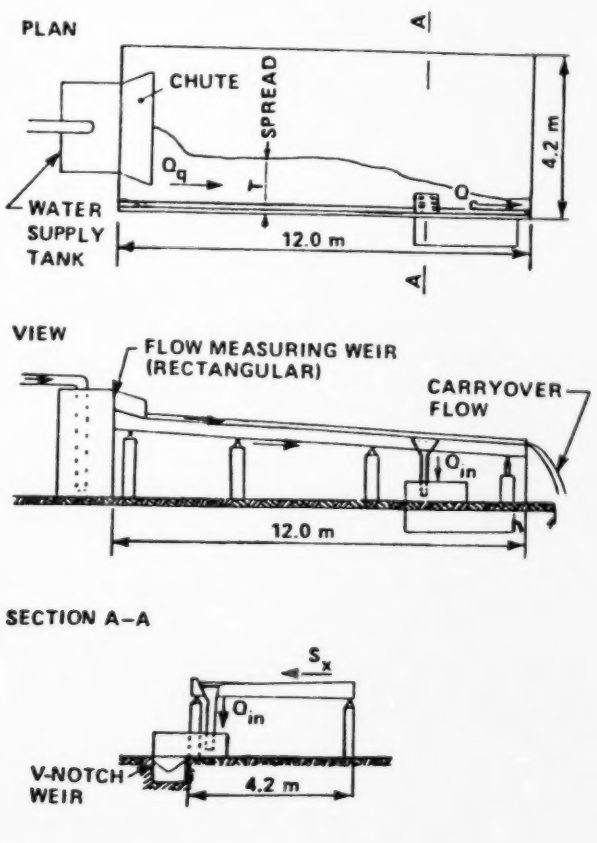


Figure 1/ Experimental Apparatus for Testing Inlets

1/ a water supply tank
2/ a roadway section with an inlet, and
3/ a water return structure.

The water supply tank delivered water to the roadway and also served to meter the gutter flow. The tank was 2.75 m wide, 3.66 m long, and 0.91 m deep. At the downstream end of the tank, a suppressed rectangular weir was placed and calibrated *in situ*. The weir head was measured by a point gauge placed inside a stilling well attached to the tank. The inflow rates to the experimental roadway were then calculated from the weir calibration equation.

The water supply tank was connected to the roadway by a wooden chute. The chute had a bottom slope of 0.40 m/m and its width increased from 1.2 m to 2.4 m over a length of 0.7 m. To reduce the velocity of water leaving the supply tank, the chute was covered with several layers of a horse-hair mattress and fitted with some baffles. This arrangement produced satisfactory inflow conditions at the upstream end of the experimental roadway.

The experimental roadway was built on a wooden platform which was 4.2 m wide and 12.0 m long. The platform was supported by three I-beams which rested on 12 pillars. Using mechanical jacks, the platform longitudinal and crossfall slopes could be easily changed. The longitudinal slope was varied from 0.003 m/m to 0.06 m/m. The crossfall slopes were varied from 0.02 m/m to 0.06 m/m, in 0.02 increments.

For the tests of inlets in a sag, vertical wooden barriers were built along the perimeter of the wooden platform. The maximum depths of ponding varied from 0.2 m to 0.3 m.

On the top of the platform, road drainage channels were installed. All the parts were made of plywood. To properly simulate the channel roughness, sand particles of 1.5 mm diameter were glued to the wood surface. This particle size was found to correspond, for a fully developed turbulent flow, to the Manning coefficient $n = 0.013$.

A square grid with fine divisions of 0.25 m and coarse divisions of 1 m was marked on the experimental roadway. This grid served for setting-up gutter flows of preselected pavement spreads.

The sewer inlets to be tested were installed, according to MTC specifications [6], about 8 m from the upstream end of the roadway. Water entering the inlet discharged into a stilling basin connected to a weir box. This box, used for taking flow measurements, was a 90° V-notch weir. The weir head was measured by a point gauge installed in a stilling well.

In sag installation tests, all roadway flow discharged through the inlet. In installations on a grade, water left the experimental roadway in two ways – either through the inlet, or as carryover flow discharged at the downstream end of the facility. The carryover flow was collected below the downstream end of the roadway and discharged into the laboratory sump.

2.2/ Experimental Procedures

Individual tests were preceded by setting up the roadway longitudinal and crossfall slopes. This was done manually by adjusting the platform supports and checking the roadway levels with an automatic levelling instrument. Typically, the actual surface elevations did not deviate from the calculated ones by more than 2 mm.

For each setting of longitudinal and crossfall slopes, inlet capacities were measured for several discharges through the roadway drainage channel, starting with small flows and increasing them gradually until the pavement spread of 3 m was reached, or the drainage channel was filled to the top of the curb. During each test run, the gutter flow rate, spread and depth (upstream of the inlet), and the inlet discharge were measured. Both the gutter and inlet discharges were measured fairly accurately by the calibrated measuring weirs. It is estimated that the accuracy of flow measurements was about 3% to 5% at the readout point.

The flow spreads were measured upstream of the inlet where the waterline was more or less parallel to the road curb. The accuracy of these measurements is estimated as ±0.10 m.

The measurements of the flow depth were complicated by the presence of surface waves. This also occurs in actual field conditions.

Inlet discharges were typically plotted as Q_{inlet} *versus* the spread and these graphs were then used to interpolate design discharges from the preselected spreads. The recommended accuracy of the interpolated discharges was ±10% and could be achieved for flows greater than 0.020 m^3/s.

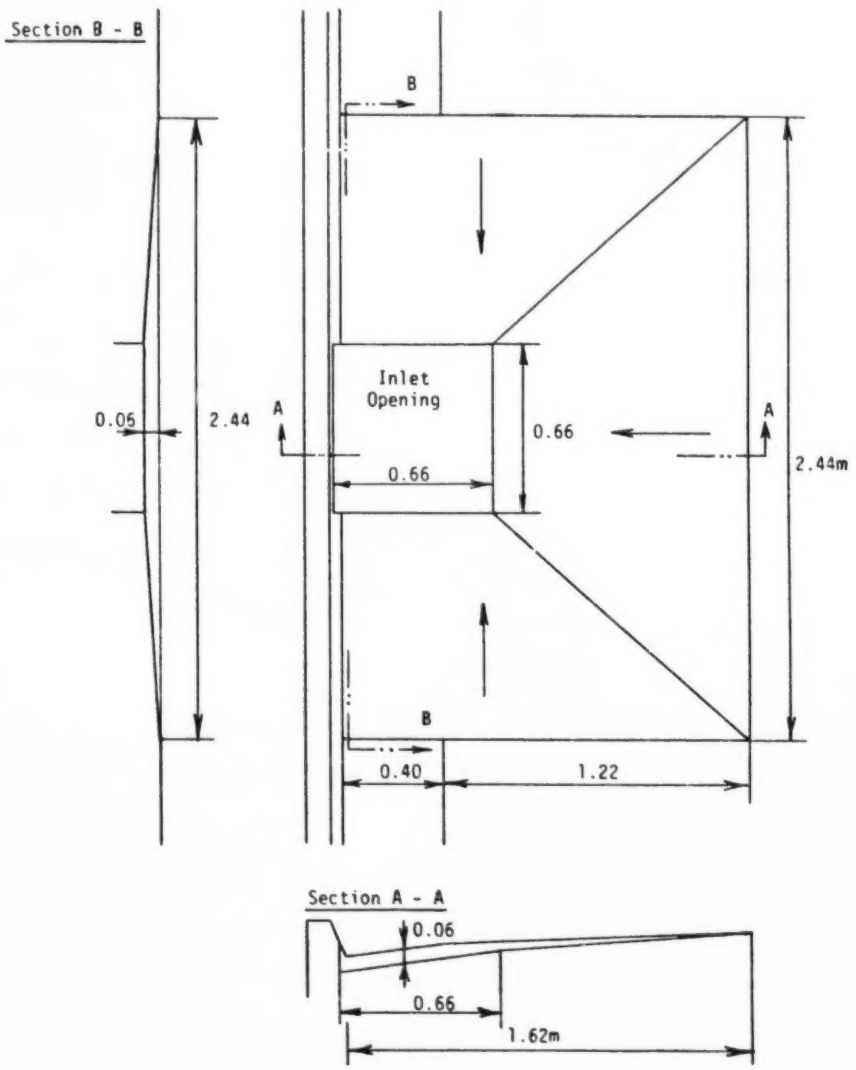


Figure 2/ Depressed Inlet Installation Tested

3/ Hydraulic Capacities of Drainage Structures Tested

As stated in the introduction, the study program consisted of seven distinctive subtasks which involved either different drainage structures or different operational conditions. The results of experiments related to these tasks are presented below in the same order as used during the experimental program.

3.1/ Depressed Inlets

Early studies of grate inlets [2] indicated that by installing depressed inlets below the road surface, it is possible to increase the effective head over the inlet and the corresponding inlet discharge capacity. On the other hand, inlet depressions create uneveness in the road surface which may disrupt the flow of traffic, contribute to higher maintenance costs, and lead to accumulation of debris and possible inlet clogging.

Consequently, depressed inlets are not popular in the Ontario drainage practice. Nevertheless, it was of interest to establish capacities of depressed inlets to see whether such benefits would offset the disadvantages listed above.

3.1.1/ Single and Twin Depressed Inlets on Grade

The terms of reference called for the evaluation of hydraulic capacities of the single and twin DD-713-A inlets installed in a 60 mm depression as shown in Figure 2. The testing program is summarized below.

Structures Tested:	Depressed Inlets (depression = 60 mm)
Inlet Grate:	DD-713-A, single and twin
Curb and Gutter:	B
Grades:	0.003 to 0.06 (m/m)
Crossfalls:	0.02 to 0.06 (m/m)
Spreads:	0.5 to 3.0 m

3.1.1.1/ Single Depressed Inlet DD-713-A

The capacities of the single depressed inlet are plotted for various grades, spreads and crossfalls in Figure 3 and the corresponding numerical values are listed in the Appendix. The discussion of results follows.

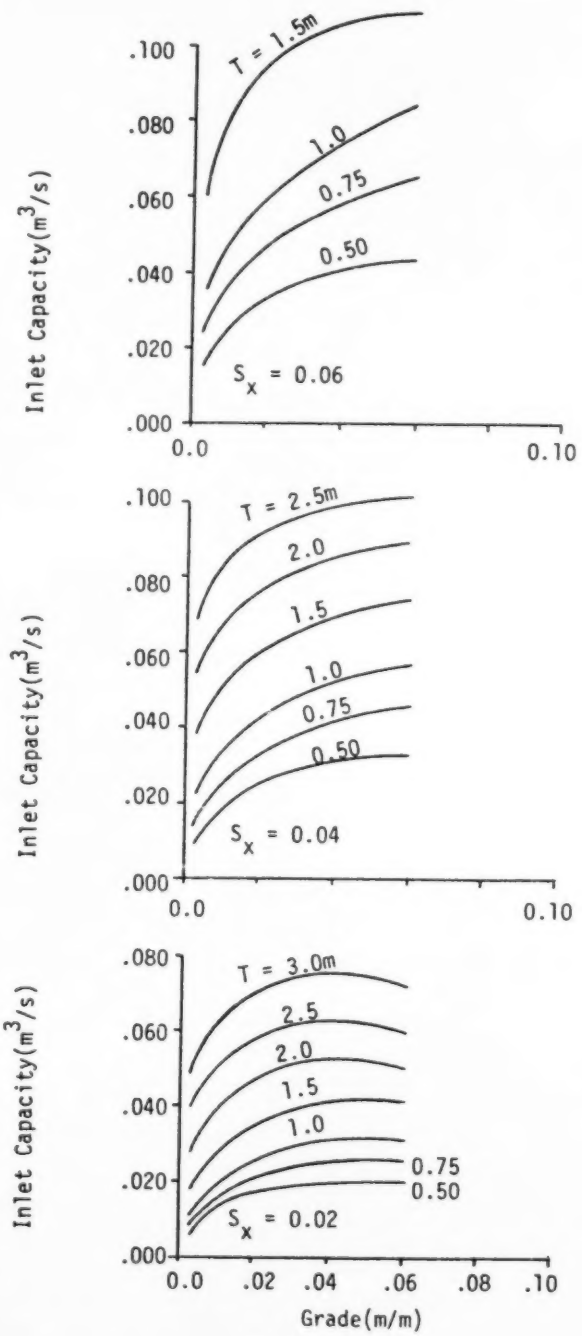


Figure 3/ Sewer Inlet Capacity: Inlet Grate DD-713-A, 60 mm Depressed, Curb and Gutter Type B

The shape of the curves Q_{inlet} *vs* grade, for the depressed inlet, is fairly similar to that reported earlier for nondepressed inlets [3]. The inlet capacity increased with the grade until it reached the maximum for grades slightly larger than 0.04 and then it decreased for steeper grades. In the rising part of the capacity curve, the inlet capacity was controlled by the limited supply of water in the gutter. Past the maximum inlet discharge, the increasing flow velocity interfered with the inlet operation and this led to the reduction in the inlet discharge. It appears that the maximum discharge for depressed inlets is reached for grades somewhat steeper than those observed for nondepressed inlets.

It was of interest to compare the capacities of depressed and nondepressed inlets. For this purpose, the areas under the capacity curves in Figure 3 were integrated for grades from 0.003 to 0.06 and compared to those corresponding to the nondepressed inlet. Such data are listed in Table 1 for various spreads and crossfalls.

It can be inferred from Table 1 that, on the average, the depressed inlet has mean capacities about 20% greater than those of the nondepressed inlet. For individual spreads and crossfalls, such deviations varied from 9 to 38% and the depressed inlet was particularly effective for greater crossfalls and smaller spreads. Comparisons for various grades indicated that the depressed inlet was more effective for intermediate grades, because on low grades (less than 0.02), the nondepressed inlet intercepts a large portion of the gutter flow and only small improvement can be achieved by depressing the inlet.

3.1.1.2/ Twin Depressed Inlet DD-713-A

The twin depressed inlet was tested for the same range of conditions as the single inlet. Twin inlet capacities are shown in Figure 4 and listed in the Appendix.

The twin depressed inlet capacities were compared to those of the single depressed inlet. On the average, the twin inlet capacity exceeded that of the single inlet by 27%. For individual spreads and crossfalls, such deviations varied from 13 to 42%. The lowest increases in capacity, obtained by twinning the inlets, were observed for small spreads when the upstream inlet intercepts almost all gutter flow and only a low flow approaches the downstream grate. The highest increases were observed for large spreads and crossfalls.

Table 1/ Mean Capacities for Depressed and Nondepressed Inlet DD-713-A, Curb and Gutter B

Crossfall S_x (m/m)	Spread T (m)	$\bar{Q}_n$ (m^3/s)	$\bar{Q}_d$ (m^3/s)	$\bar{Q}_d/\bar{Q}_n$ (-)	$\bar{Q}_{td}$ (m^3/s)	$\bar{Q}_{td}/\bar{Q}_d$ (-)
0.02	0.5	.0134	.0179	1.34	.0203	1.13
	0.75	.0181	.0229	1.27	.0275	1.20
	1.00	.0221	.0278	1.26	.0330	1.19
	1.50	.0300	.0372	1.24	.0424	1.14
	2.00	.0442	.0483	1.09	.0571	1.18
	2.50	.0536	.0597	1.11	.0726	1.22
	3.00	.0654	.0717	1.10	.0880	1.23
0.04	0.50	.0197	.0271	1.38	.0311	1.15
	0.75	.0292	.0369	1.23	.0438	1.19
	1.00	.0371	.0466	1.26	.0568	1.22
	1.50	.0544	.0638	1.17	.0860	1.35
	2.00	.0710	.0798	1.12	.1132	1.42
	2.50	.0836	.0948	1.13	.1330	1.40
0.06	0.50	.0268	.0357	1.33	.0407	1.14
	0.75	.0386	.0531	1.38	.0648	1.22
	1.00	.0536	.0649	1.23	.0884	1.34
	1.50	.0773	.0991	1.28	.1287	1.30
		$\Sigma = .7381$	$\Sigma = .8883$	1.20	$\Sigma = 1.1274$	1.27

$\bar{Q}_n$ = Mean discharge (for $0.03 \leq G \leq 0.06$, G = grade) for the nondepressed inlet DD-713-A

$\bar{Q}_d$ = Mean discharge ($0.03 \leq G \leq 0.06$) for depressed inlet DD-713-A

$\bar{Q}_{td}$ = Mean discharge ($0.003 \leq G \leq 0.06$) for twin depressed inlet DD-713-A

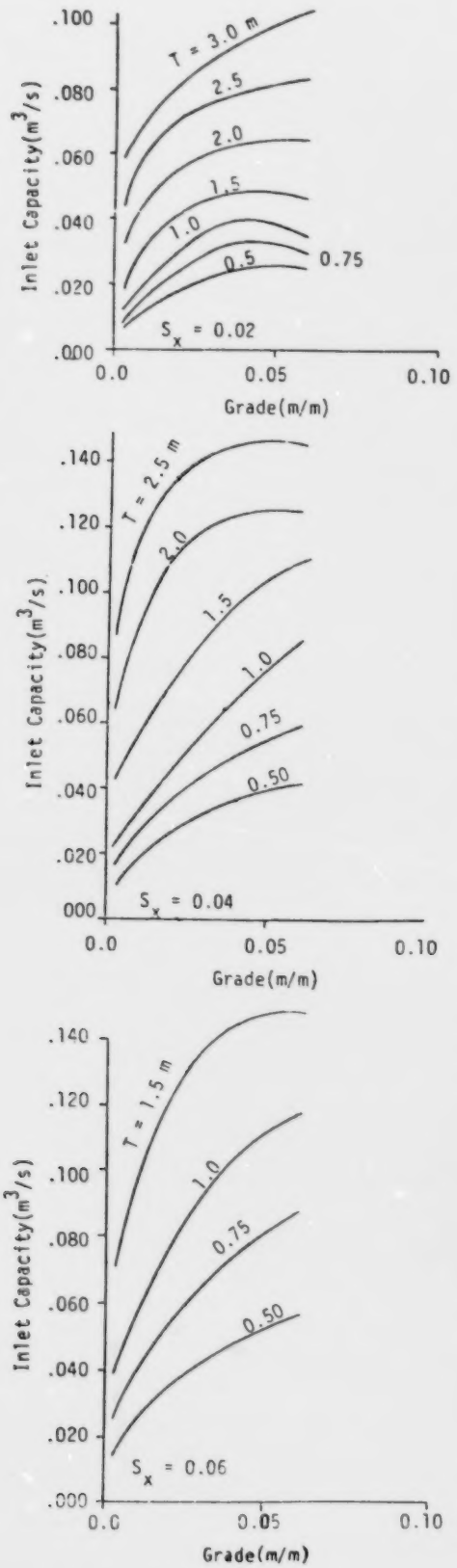


Figure 4/ Sewer Inlet Capacity: Twin Inlet Grate DD-713-A, 60 mm Depressed, Curb and Gutter Type B

3.1.2/ Depressed Inlets in Sag

Both the single and twin DD-713-A inlets were tested in a sag. The results of these tests are shown in Figure 5 in two ways: firstly, the depth of ponding was measured in the depression (above the grate) and secondly, it was measured outside of the depression, from the deepest point in the gutter. In the former case, there is practically no difference between the curves reported for depressed and nondepressed inlets.

The second set of curves was produced for the depths measured outside of the depression. These curves were produced for both the single and twin inlets by reducing the depth of ponding by the depression depth – 0.06 m. It is obvious from Figure 5, that by depressing the inlet, its capacity is increased for a given depth of ponding on the road surface. For the single inlet, this increase varied from 0.017 to 0.065 m^3/s. The mean value corresponding to the range of depths from 0.00 to 0.20 m was 0.046 m^3/s.

For the twin depressed inlet, the increase in the capacity obtained by depressed installation varied from 0.025 to 0.095 m^3/s and the mean value corresponding to the range of depths from 0.00 to 0.15 m was 0.060 m^3/s.

In summary, the depression of inlet grates leads to increased capacities of both single and twin inlets on grade as well as in sag. On grade, the average capacity increases were determined for single and twin inlets as 20 and 27%, respectively. The smallest increases were noted for low grades and small spreads, where single nondepressed inlets operate rather effectively. Inlet depressions were found to be highly effective in a sag. In general, though, inlet depressions have some adverse effects on traffic, maintenance, and inlet operation. Implementation of depressed inlets in drainage practice should be considered after thorough evaluation of experimental depressed inlets in the field.

3.2/ Inlet Capacities for Small and Large Spreads

To extend the earlier results produced in Reference 3, two common MTC grate inlets were studied under two extreme conditions – very small spreads with no carryover flow and large spreads in installations with concrete barriers.

3.2.1/ Inlet Capacities With No Carryover

In typical situations, sewer inlets on grades are designed to intercept a portion of the gutter flow and the remaining carryover flow bypasses the inlet and is fully or partly intercepted by the next downstream inlet. In special cases, however, the inlet is required to intercept all the gutter flow without allowing any carryover. To provide data for such cases, inlet capacities with no carryover were studied for the conditions listed below.

Inlets Tested:	DD-713-A, DD-713-B, and DD-705
Curb and Gutter:	A, B and D
Grades:	0.003 - 0.06 m/m
Crossfalls:	0.02 - 0.06 m/m

To establish maximum inlet discharges with no carryover, the gutter flow in the roadway apparatus was gradually increased until a small carryover was observed. The gutter flow was then slightly reduced to eliminate the carryover flow and the inlet discharge, equal to the gutter flow, was taken as the maximum inlet capacity with no carryover (100% interception). The experiments were conducted for a relatively large crossfall (0.06 m/m) to obtain a good control of the flow spread on the roadway surface. The observed data are plotted in Figure 6 and listed in the Appendix.

The plots of Q_{inlet} (no carryover) *vs* grade have a characteristic shape which is common for all the grates and curbs tested. On very low grades, the gutter flow limits the full-interception grate capacity which reaches its maximum at a grade of about 0.01 m/m. With an increasing grade, the fully intercepted flow starts to drop off rapidly to about 20 to 30% of the maximum for the grade of 0.06 m/m. It was observed that with the increasing grade, the flow velocity rapidly increased and, eventually, some water passed or jumped over the grate. The fully-intercepted flow curves were further extrapolated to the grade of 0.10 m/m.

When comparing various grate designs, it was noted that the grate DD-713-A (i.e., the grate with bars parallel to the curb) provided the highest fully intercepted flows for grades smaller than 0.04 m/m. For steeper grades, the grade DD-705 (V-shape) produced slightly better results, because this grate design facilitates a better flow concentration over the grate face at high flow velocities.

The effects of the curb shape on fully intercepted flows were only minor and could be observed only in the region of low grades (less than 0.01 m/m) where the inlet capacity is controlled by the gutter flow. For steeper grades, the data obtained for curbs and gutters A and B were practically identical and were therefore grouped together.

It should be mentioned that the condition of full flow interception was found rather severe. In most experiments (grades greater than 0.02 m/m), the fully intercepted flow was smaller than the full-gutter flow. Only on low grades, the flows of widths equal to or slightly greater than the gutter width could be fully intercepted. It was noted that if the no-carryover condition is somewhat relaxed by allowing carryover flows smaller than

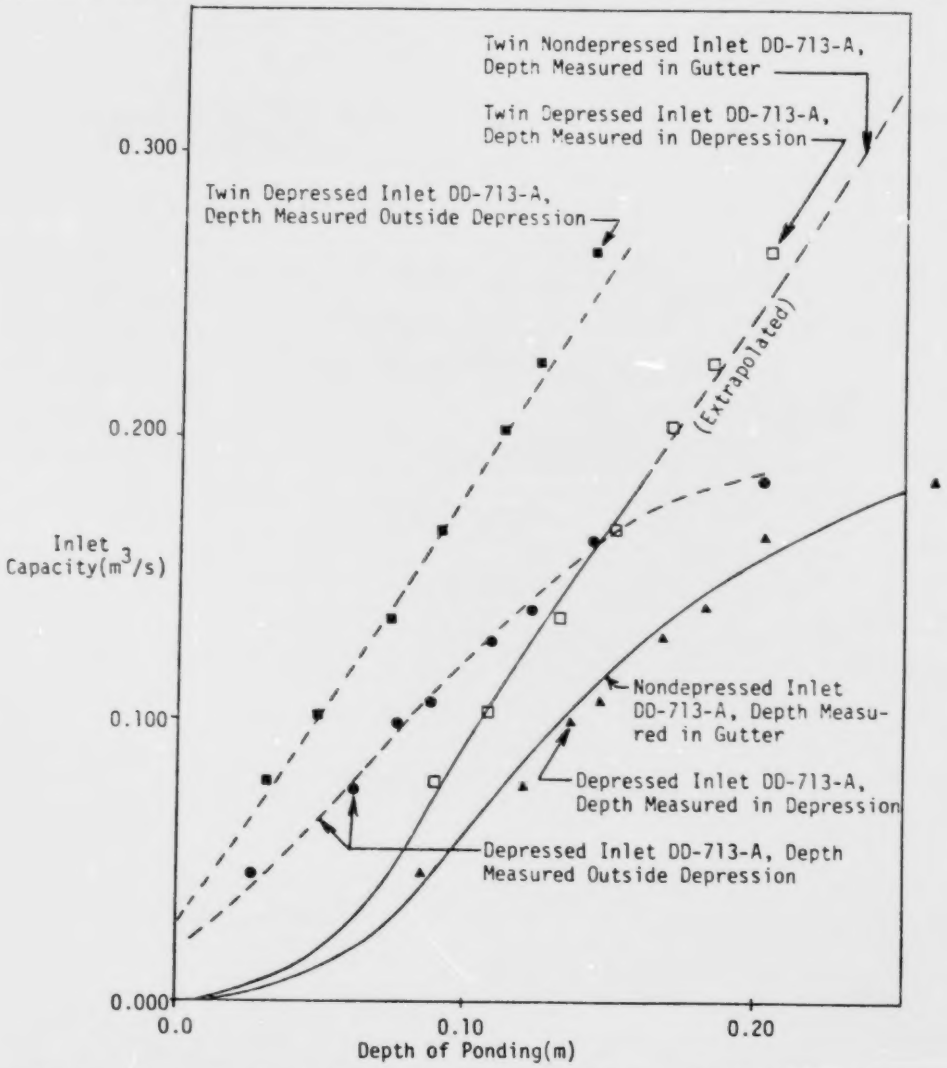


Figure 5/ Capacity Curves of Single and Twin Depressed and Nondepressed Inlets DD-713-A in a Sag

0.001 m^3/s, much higher inlet discharges would be obtained. In fact, such discharges exceeded those in Figure 6 by up to 50%.

In summary, the full-interception inlet capacity is controlled by the gutter flow for grades smaller than 0.01 m/m and by the road grade for steeper grades. Such capacity diminished rapidly with grades steeper than 0.01 m/m. In terms of mean intercepted flows for the full range conditions studied, the highest capacity was found for grate DD-713-A, followed by DD-705 with an almost identical capacity, and DD-713-B which had capacities about 30% smaller. The differences in inlet capacities for curbs and gutters A and B were so small that a single design curve was adopted for both types.

3.2.2/ Inlet Capacities for Large Spreads

In inlet installations next to a concrete barrier, relatively large flow depths and spreads can be encountered. Such conditions could not be reproduced in the road drainage apparatus because of physical limitations. To evaluate the functioning of inlets under high flow depths, a special test installation was built in the 1 m flume of the Hydraulics Laboratory at NWRI.

A wooden floor was installed in the flume, 0.25 m above the flume bottom and the grate DD-713-A was installed in this floor. For operational reasons, the maximum grade and depth were 0.03 m/m and 0.28 m, respectively. Because of the limited flume width, the experimental conditions employed represented only a narrow strip of the roadway, more or less the gutter and an additional 0.6 m strip of the pavement. In this installation, field conditions with lateral inflow cannot be fully duplicated. Nevertheless, the installation offered the only opportunity to investigate inlets under large flow depths and similar installations have been used by others for inlet testing.

The experimental results for grate DD-713-A are plotted in Figure 7 as plots of Q_{inlet} *vs* the flow depth. Numerical data are listed in the Appendix.

It can be inferred from Figure 7 that inlet capacity increases sharply with the flow depth and this increase is further affected by the road crossfall, though such effects seem to diminish at higher depths of flow. Differences between the flume data and the data collected earlier in the roadway apparatus seem to be larger for small depths of flow and gradually decreased with the increasing flow depth.

Under such circumstances, it was realistic to use the graphs in Figure 7 for extrapolation of inlet data for various crossfalls and depths greater than 0.15 m. Data extrapolations for other inlet grates and grades could not be verified against the flume data and their reliability would be questionable.

In summary, a special installation in the 1 m flume made it possible to test the inlet DD-713-A for grades up to 0.03 m/m and the depths of flow up to 0.28 m. Using such data, the earlier produced inlet capacities were extrapolated for the flow depths ranging from 0.17 m to 0.25 m.

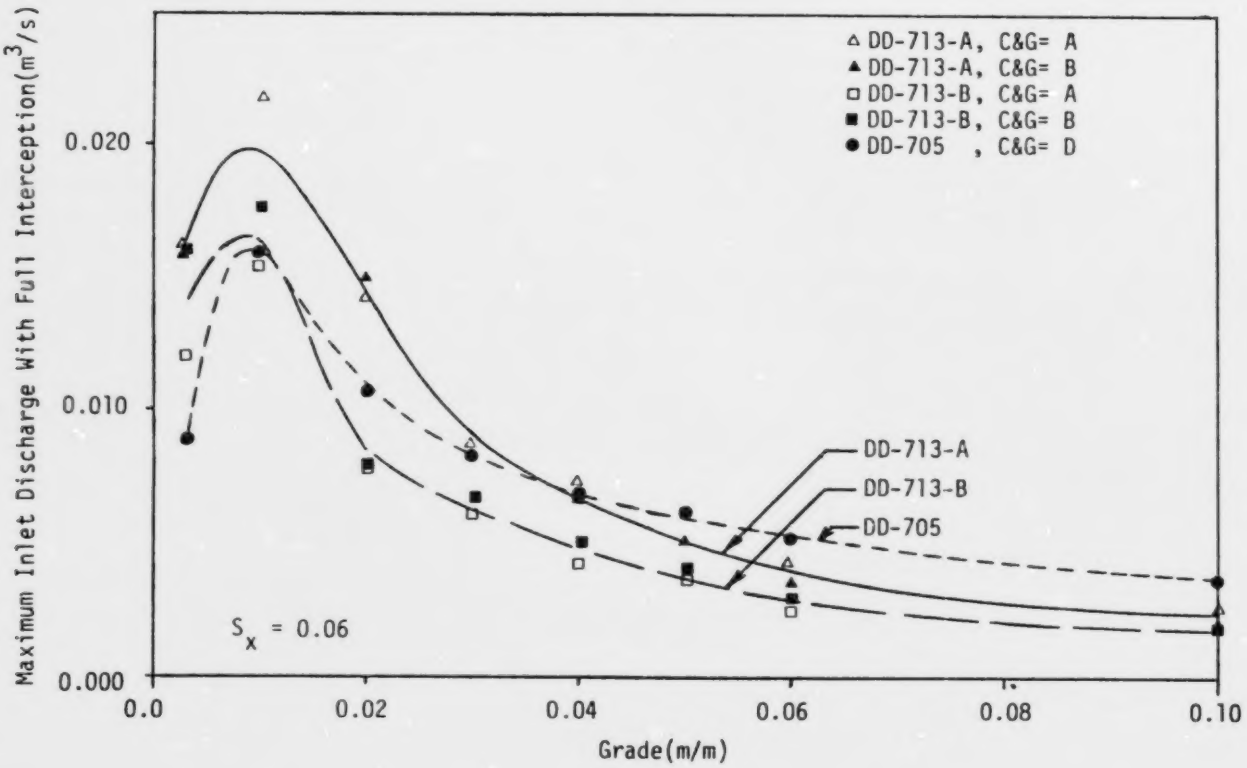


Figure 6/ Maximum Inlet Discharges with Full Interception

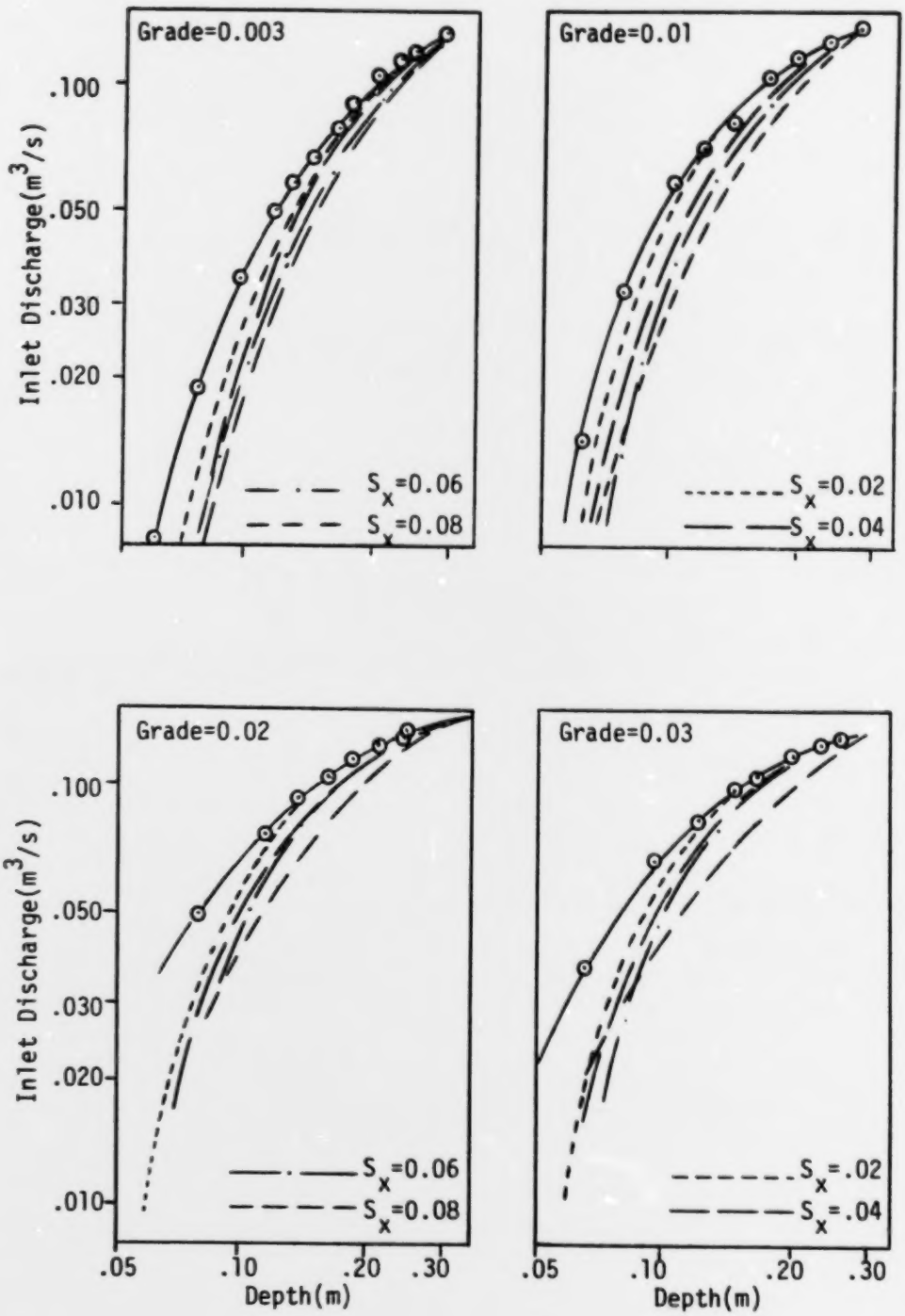


Figure 7/ Discharge Capacities of Grate DD-713-A (Curb & Gutter B) for Various Grades, Crossfalls and Flow Depths

3.3/ Ductile Iron Grate

CANRON Inc. has developed a new grate made of ductile iron (see Figure 8). Although the grate size is about the same as that of the conventional MTC designs, the use of ductile iron makes it possible to reduce the width of grate bars (13 mm) to about one-half of the conventional width (25.4 mm). By reducing the bar width, the total area of grate openings was increased from 0.14 m^2 (conventional MTC design DD-713-A) to 0.2023 m^2 (the ductile iron grate). On the other hand, the ductile iron did not have the wide slot, parallel to the curb, which is incorporated in the MTC grates DD-713-A and B.

The ductile iron grate was tested for the range of conditions listed below.

Grate:	Ductile Iron Grate (CANRON)
Curb and Gutter:	B
Grades:	0.003 - 0.06 m/m
Crossfalls:	0.02 - 0.06 m/m
Spreads:	0 - 3.0 m (without overtopping the curb)

The observed inlet capacities are plotted in Figure 9 and listed in the Appendix. The discussion of results follows.

The capacity curves of the ductile iron grate in Figure 9 are similar to those reported earlier for MTC grates [3]. The grate capacity first increases with the grade and once the gutter flow velocity strongly interferes with the grate operation, the capacity starts to decrease.

It was of interest to compare the ductile iron grate against the DD-713-B grate in terms of capacities. It was noted that depending on the grade, crossfall and spread, the ductile iron grate capacity ranged from 70% to 110% of that of the DD-713-B grate, with the average value of 86%. Thus the ductile iron grate appears only slightly less efficient than the standard

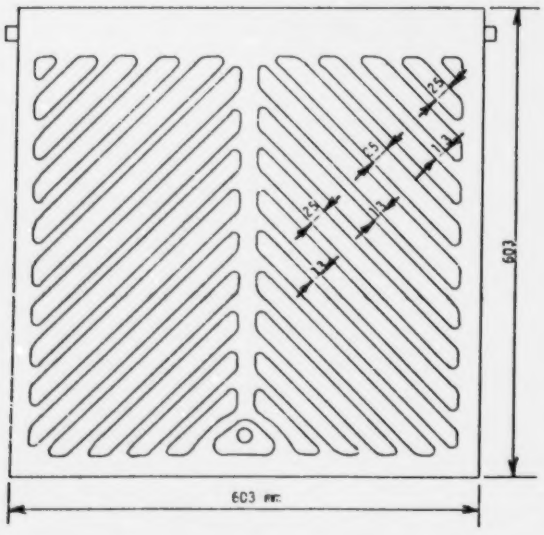


Figure 8/ Ductile Iron Grate (CANRON)

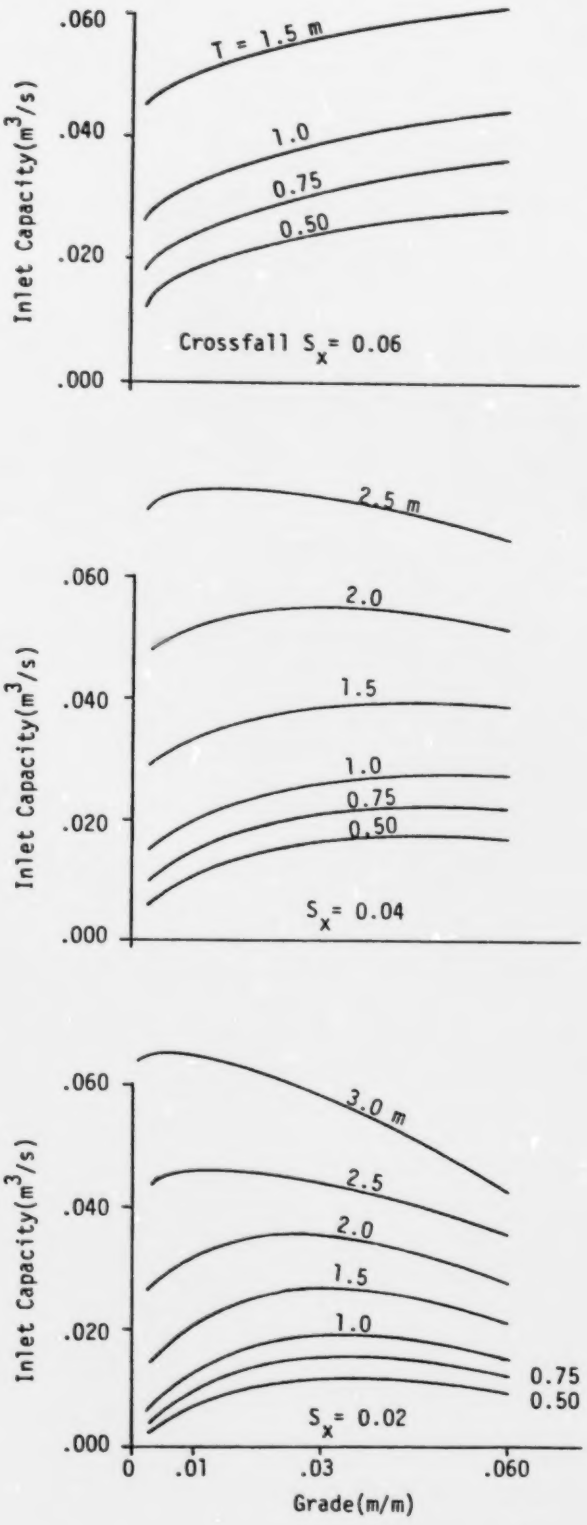


Figure 9/ CANRON Ductile Iron Grate Capacities for Various Spreads, Crossfalls and Grades

design. It is conceivable that by incorporating the slot next to the curb, which was found to contribute greatly to the grate capacity, in the ductile iron grate, the capacity of such a modified grate would exceed that of the conventional grates DD-713-A and B. It is also speculated that in sags, the ductile iron grate capacity will exceed that of the conventional MTC designs for greater depths of ponding, when the grate starts to operate as an orifice and its discharge is directly proportional to the total area of openings.

In summary, the ductile iron grate has desirable features, such as the low weight, high grate porosity and good capacity. The design tested could be further improved by adopting the slot next to the curb which is incorporated in the conventional MTC grates.

3.4/ Combination Inlets

Combination inlets provide both curb and grate openings, thus combining advantages of curb and grate inlets. Common combination inlets have curb openings directly opposite to the grate and their use seems particularly beneficial in sags.

In the earlier phase of the study, the combination inlet C-93 was investigated. This inlet, which combines the grate frame and the curb section with four small openings in a single structure, had capacities on grade smaller than those of the common MTC grate inlets. In the current phase, two other combination inlets, derived from the Burlington combination inlet [1], were investigated.

The combination inlets tested combine the standard DD-713-A and B grates with a separate curb section which is installed in the concrete curb. The area of the curb opening is about 0.078 m^2, thus bringing the total area of combination inlet openings to 0.224 m^2 and 0.213 m^2 for grates DD-713-A and DD-713-B, respectively. The latter design is shown in Figure 10.

The main purpose of the experimental program was to expediently evaluate the combination inlets in terms of their capacities. The range of experimental conditions is listed below.

Inlets Tested:	DD-713-A and B
Curb and Gutter:	B
Installations:	On Grade and in Sag
Grades:	0.003 - 0.02 m/m
Crossfalls:	0.02 - 0.06 m/m
Spreads:	0.5 - 3.0 m (no overtopping of the curb)

The experimental results for both combination inlets are presented in Tables 2 and 3, together with some data for standard grate designs. It is evident from Tables 2 and 3 that the combination inlets have higher capacities than the corresponding grate inlets. This increase in capacity varied for various crossfalls from 6 to 23%, with an average value of 13%. For the common crossfall of 0.02 m/m, the additional capacity obtained by adding the curb opening to the grate inlets was about 7% and such an improvement is hardly significant. Larger increases (up to 23%) in the capacity were found for steeper crossfalls of 0.04 and

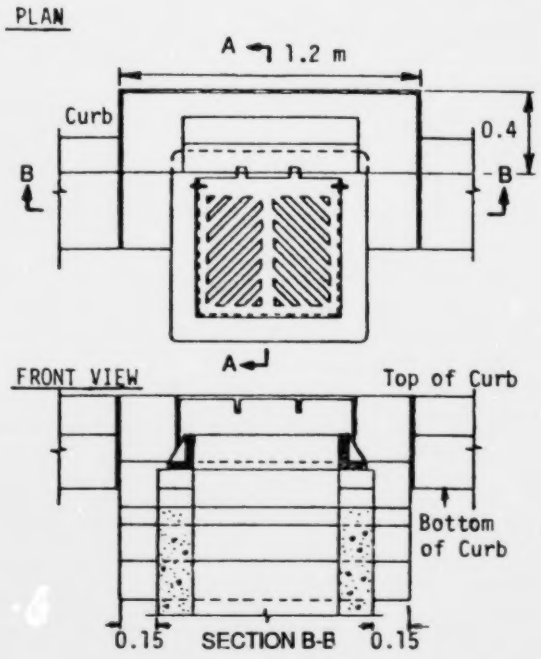


Figure 10/ (Burlington) Combination Inlet

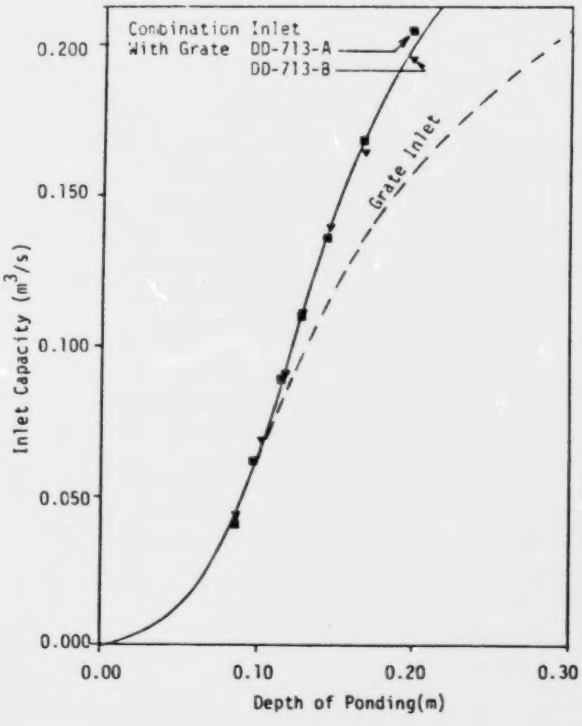


Figure 11/ Capacities of Combination Inlets in a Sag

Table 2/ Capacities of Combination Inlet Derived from Grate DD-713-A (Curb and Gutter B)

Crossfall (m/m)	Spread (m)	Inlet Discharge (m^3/s)			Sum of Flow for all three grades		$\frac{Q_{comb}}{Q_{grate}}$
		Grade (m/m)			Q_{comb} (m^3/s)	Q_{grate}* (m^3/s)	
		0.003	0.01	0.02			
0.02	.50	.0065	.0115	.0150	.0330	.0225	1.47
	.75	.0990	.0145	.0190	.0425	.0368	1.15
	1.00	.0120	.0180	.0230	.0530	.0485	1.09
	1.50	.0160	.0260	.0325	.0745	.0708	1.05
	2.00	.0260	.0390	.0440	.1090	.1060	1.03
	2.50	.0410	.0510	.0560	.1480	.1444	1.02
	3.00	.0480	.0630	.0660	.1770	.1731	1.02
	Sum of Discharges	.1585	.2230	.2555	.6370	.6021	1.06
0.04	.50	.0110	.0170	.0230	.0510	.0384	1.33
	.75	.0165	.0245	.0310	.0720	.0621	1.16
	1.00	.0215	.0320	.0390	.0925	.0836	1.11
	1.50	.0365	.0490	.0610	.1465	.1352	1.08
	2.00	.0540	.0710	.0910	.2160	.1918	1.13
	2.50	.0790	.0910	.1020	.2720	.2301	1.18
	Sum of Discharges	.2185	.2845	.3470	.8500	.7412	1.15
0.06	.50	.0160	.0270	.0350	.0780	.0485	1.61
	.75	.0245	.0400	.0470	.1115	.0869	1.28
	1.00	.0340	.0520	.0580	.1440	.1303	1.11
	1.50	.0580	.0750	.0970	.2300	.2058	1.12
	Sum of Discharges	.1325	.1940	.2370	.5635	.4715	1.20
Sum of Discharges for all Crossfalls		.5095	.7015	.8395	2.0505	1.8148	1.13

* *Data from Reference 3*

0.06 m/m. In all cases, the combination inlet with grate DD-713-A had capacities about 9% greater than that with grate DD-713-B.

It appears that combination inlets on grade have capacities comparable to those of similar grate inlets. The orientation of the curb opening which is almost parallel to the flow velocity vector, a slight offset of the opening inside the curb, and a reduced head over the opening, explain the low hydraulic effectiveness of the curb opening. For higher crossfalls, the effectiveness of the curb opening increases because of increased lateral inflow.

Both combination inlets were also tested in a sag and the results of these tests are shown in Figure 11 and listed in the Appendix. Both inlets had similar capacities which in the region of low depths (less than 0.10 m) did not differ much from those corresponding to the grate inlets. At higher depths of ponding, where a transition in the inlet operation from the weir mode to the orifice mode takes place, the combination inlet capacity started to rise above the grate inlet capacity. For the highest depth of ponding (about 0.21 m), the combination inlets conveyed about 27% more flow than the grate inlets. Assuming that both the grate and curb opening operate as an orifice, the curb opening should contribute about 31% of the flow at higher ponding depths.

In summary, only limited additional capacity can be obtained by adding a relatively small curb opening to grate inlets on grade. Greater benefits can be derived in sag installations where the combination inlet conveys about 30% more flow than the corresponding grate inlet at higher depths of ponding ($\geq$ 0.22 m). The main advantage of the combination inlets seems to be their ability to provide some relief (through the curb opening) should the grate become clogged.

3.5/ Round Frame Grate

Round frame grates have been introduced recently by McCoy Foundry to allow for machining of grate and frame seats and thereby to achieve a perfect setting of grates in frames. Consequently, the rocking motion of grates and the resulting damage can be avoided. The round frame grate tested is shown in Figure 12. The grate has bars arranged diagonally, pointing towards the curb in the downstream direction and there is no central supporting crossbar. The total area of grate openings is 0.1225 m^2 and this represents about 84% and 91% of the opening area of grates DD-713-A and DD-713-B, respectively.

To evaluate the round frame grate, limited tests were conducted for the range of conditions listed below:

Inlet: Round Frame Grate, With Diagonal Bars (McCoy)
Curb and Gutter: B
Installation: On Grade and in Sag
Grades: 0.003 to 0.02 m/m
Crossfalls: 0.02 to 0.06 m/m
Spreads: 0.5 to 3.0 (no curb overtopping)
Depth of Ponding: 0.00 to 0.26 m

Observed discharges of the round frame grate are shown in Table 4 together with discharges of conventional MTC grates DD-713-A and B. For the limited range of tests, the round frame grate capacity increased with the increasing grade, crossfall and spread. In comparison to the MTC grates, the round frame grate had two features of merit – the diagonally oriented bars direct the flow towards the curb and there is no central support which could disturb the flow.

Table 3/ Capacities of Combination Inlet Derived from Grate DD-713-B (Curb and Gutter B)

Crossfall (m/m)	Spread (m)	Inlet Discharge (m^3/s) Grade (m/m)			Sum of Flow for all three grades		$\frac{Q_{comb}}{Q_{grate}}$
		0.003	0.01	0.02	Q_{comb} (m^3/s)	Q_{grate}* (m^3/s)	
0.02	.50	.0060	.0110	.0154	.0324	.0217	1.49
	.75	.0080	.0145	.0187	.0412	.0336	1.26
	1.00	.0110	.0180	.0220	.0510	.0428	1.19
	1.50	.0170	.0265	.0310	.0745	.0642	1.16
	2.00	.0230	.0350	.0410	.0990	.0984	1.01
	2.50	.0345	.0460	.0520	.1325	.1323	1.00
	3.00	.0430	.0550	.0604	.1584	.1474	1.01
	Sum of Discharges	.1425	.2060	.2405	.5890	.5504	1.07
0.04	.50	.0103	.0180	.0230	.0513	.0365	1.41
	.75	.0150	.0250	.0300	.0700	.0603	1.16
	1.00	.0220	.0320	.0370	.0910	.0772	1.18
	1.50	.0360	.0480	.0540	.1380	.1273	1.08
	2.00	.0510	.0640	.0730	.1880	.1759	1.07
	2.50	.0650	.0770	.0880	.2300	.2158	1.07
	Sum of Discharges	.1993	.2640	.3050	.7683	.6930	1.11
0.06	.50	.0180	.0260	.0340	.0780	.0459	1.70
	.75	.0270	.0380	.0450	.1100	.0794	1.39
	1.00	.0345	.0490	.0530	.1365	.1202	1.14
	1.50	.0530	.0640	.0790	.1960	.1787	1.10
	Sum of Discharges	.1325	.1770	.2110	.5205	.4242	1.23
Sum of Discharges for all Crossfalls		.4743	.6470	.7565	1.8778	1.667	1.13

* *Data from Reference 3*

Table 4/ Capacities of the Round Frame Grate (Curb and Gutter B)

Crossfall (m/m)	Spread (m)	Inlet Discharge (m^3/s) Grade (m/m) 0.003	0.01	0.02	Q_{ref} (m^3/s)	Q_{713-A} (m^3/s)	Q_{713-B} (m^3/s)	$\frac{Q_{RF}}{Q_{713-A}}$	$\frac{Q_{RF}}{Q_{713-B}}$
0.02	.50	.0070	.0115	.0140	.0325	.0225	.0217	1.44	1.50
	.75	.0080	.0140	.0170	.0390	.0368	.0336	1.06	1.16
	1.00	.0100	.0160	.0190	.0450	.0485	.0428	.93	1.05
	1.50	.0160	.0225	.0260	.0645	.0708	.0642	.91	1.00
	2.00	.0230	.0290	.0340	.0860	.1060	.0984	.81	.87
	2.50	.0310	.0350	.0420	.1080	.1444	.1323	.75	.82
	3.00	.0400	.0440	.0480	.1320	.1731	.1574	.76	.84
	Sum of Discharges	.1350	.1720	.2000	.5070	.6021	.5504	.84	.92
0.04	.50	.0100	.0150	.0200	.0350	.0384	.0365	.91	.96
	.75	.0155	.0205	.0270	.0630	.0621	.0603	1.01	1.04
	1.00	.0205	.0250	.0320	.0775	.0836	.0772	.93	1.00
	1.50	.0325	.0340	.0420	.1085	.1352	.1273	.80	.85
	2.00	.0455	.0440	.0550	.1445	.1918	.1759	.75	.82
	2.50	.0580	.0550	.0650	.1780	.2301	.2158	.77	.82
	Sum of Discharges	.1820	.1935	.2410	.6165	.7412	.6930	.83	.89
0.06	.50	.0160	.0220	.0270	.0650	.0485	.0459	1.42	1.42
	.75	.0230	.0310	.0350	.0890	.0869	.0794	1.02	1.12
	1.00	.0330	.0380	.0390	.1100	.1303	.1202	.84	.92
	1.50	.0490	.0500	.0570	.1560	.2058	.1787	.76	.87
	Sum of Discharges	.1210	.1410	.1580	.4200	.4715	.4242	.89	.99
Sum of Discharges for all Crossfalls		.4380	.5065	.5990	1.5435	1.8148	1.6676	.85	.93

* *Data from Reference 3*

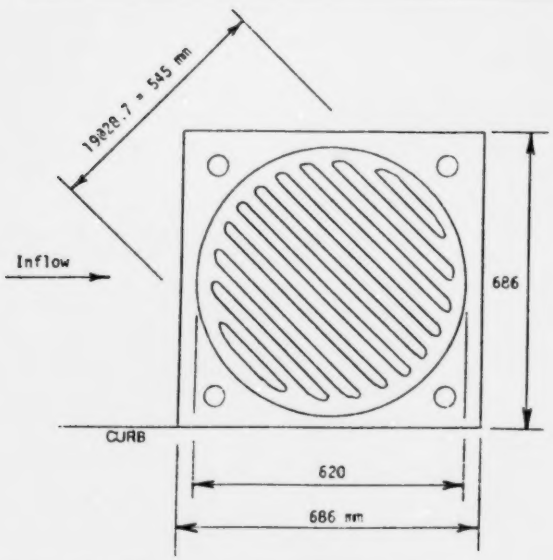


Figure 12/ Round Frame Grate (McCoy)

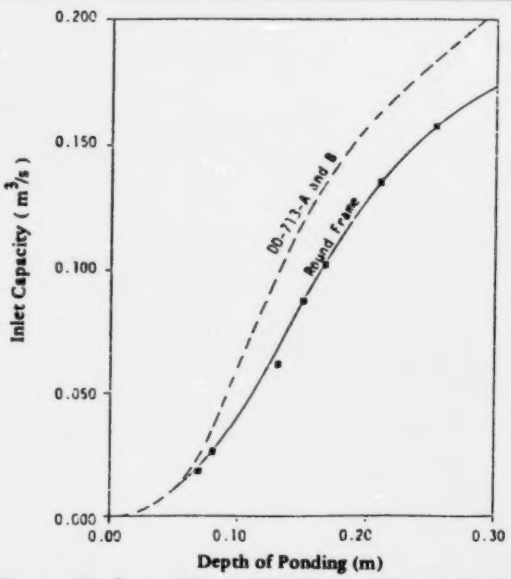


Figure 13/ Capacities of the Round Frame Grate in Sag

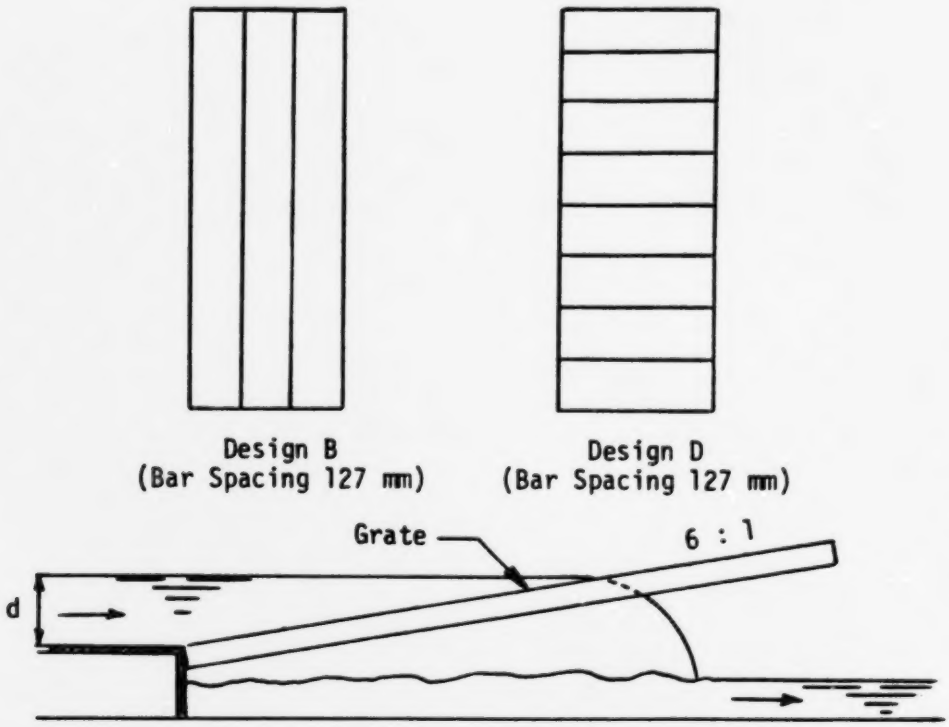


Figure 14/ Ditch Inlet Grates Tested

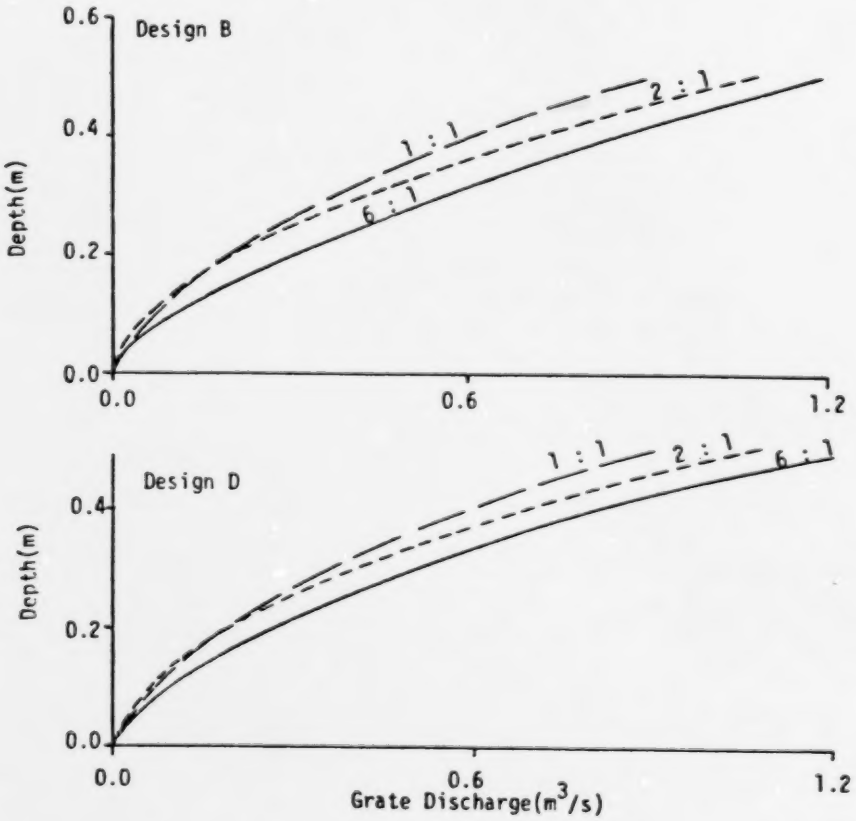


Figure 15/ Capacity Curves for Ditch Inlet Designs B and D

On the other hand, the grate has a somewhat lower porosity. When comparing discharges, the flows intercepted by the round frame grate were lower than those intercepted by grates DD-713-B and DD-713-A, by 7 and 15%, respectively.

The round frame grate was also tested in a sag. The results of these tests are shown in Figure 13 and listed in the Appendix. The round frame grate had somewhat lower (≈15%) capacities than the MTC grates DD-713-A and B, which is in agreement with the relation of grate opening areas of these three designs.

In summary, the new round frame grate performed much better than the similar design tested earlier. The round grate has somewhat lower capacities (7 to 15%) than the MTC grates, but it should produce lower maintenance costs. Further improvement of the grate tested would be possible by incorporating a slot parallel to the curb in this design.

3.6/ Ditch Inlets

Ditch inlets serve for removal of drainage water from highway medians and other drainage ditches. Such inlets are designed as drop structures which have the inflow openings covered by grates with various face slopes and bar arrangements. In an earlier study phase, five grate designs with slopes 1:1 and 2:1 were tested [3]. In this phase, such tests were slightly expanded by testing two of the original designs on a slope of 6:1. The two designs tested can be described as grates with longitudinal and crossbar arrangements with a bar spacing of 127 mm. Both designs are shown in Figure 14.

The testing of ditch inlets was done in the 1 m flume where the inlet grates were installed on a slope of 6:1. The depth of flow in the flume was gradually increased from 0.03 m to 0.3 m and the inlet discharge was measured. The observed data were then converted from the actual width of 0.38 m to a unit width of 1 m and plotted in Figure 15. The digitized data for the design curves are listed in the Appendix.

Both grates performed similarly and conveyed comparable flows. For a constant flow depth, the grate capacity of both designs increased with the decreasing slope of the grate. In fact, for identical depths, the grate with the slope of 6:1 conveyed flows about one third greater than those conveyed by the same grate on a slope of 1:1. This increase seems to follow from the larger flow area and the associated head for grates with flatter slopes.

In summary, both ditch inlet grates with longitudinal bars and crossbars produced similar rating curves and, compared to the steeper grates, the designs with the slope of 6:1 yielded higher discharges for identical flow depths.

3.7/ Gutter Outlets

Gutter outlets are lateral channels which are used to remove drainage water from the gutter. Various types of such structures, with different cross-sections and alignment, are used in road drainage practice. Budgetary constraints limited the number of outlets tested to the three types listed below in the description of the test program.

Outlets Tested:	45° Outlet (617-A), 45° Outlet – End of the Run (617-C), and 90° Outlet (616-A)
Curb and Gutter:	A (where applicable)
Installation:	617-A and 617-C on Grade
Grade:	0.003 to 0.04 m/m
Crossfall:	0.02 to 0.06 m/m
Spread:	0.5 to 3.0 m

3.7.1/ Outlets on Grade

Gutter outlets function similarly as curb inlets. Their hydraulic effectiveness is controlled by the depth of flow and the lateral velocity components.

Discharges observed for the 45° gutter outlet (617-A, see Figure 16) are listed in the Appendix and summarized in Table 5. These data indicate that the outlet discharge increased slightly with the increasing grade and then levelled off at grades of about 0.02 to 0.03 m/m. Past this limit, the outlet discharge decreased as

Table 5/ Summary of 45° Outlet Capacities

Crossfall	Grade (m/m)								
	.003			.01			.04		
	Q^*_{out} (m^3/s)	$\frac{Q_{out}}{Q_{713\text{-}A}}$	$\frac{Q_{out}}{Q_{713\text{-}B}}$	Q_{out} (m^3/s)	$\frac{Q_{out}}{Q_{713\text{-}A}}$	$\frac{Q_{out}}{Q_{713\text{-}B}}$	Q_{out} (m^3/s)	$\frac{Q_{out}}{Q_{713\text{-}A}}$	$\frac{Q_{out}}{Q_{713\text{-}B}}$
0.02	.1539	.95	1.05	.1809	.85	.91	.1944	.71	.74
0.04	.0880	1.18	1.33	.1062	.93	.96	.1084	.65	.67
0.06	.0760	1.13	1.25	.0978	1.03	1.07	.0938	.69	.73
Mean		1.05	1.16		.91	.96		.69	.72

Q^*_{out} = The sum of 45° outlet discharges for all spreads investigated

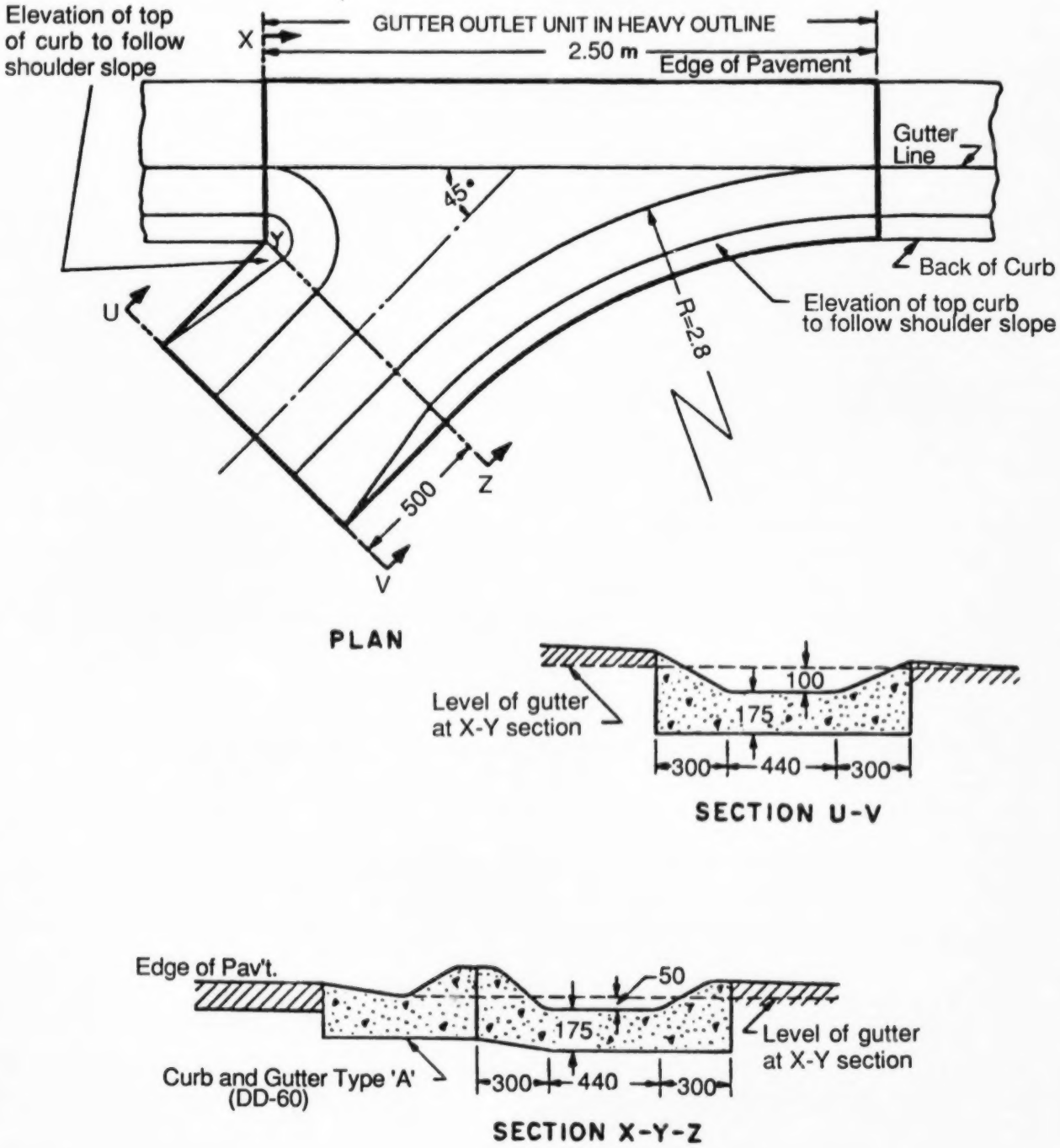


Figure 16/ 45° Gutter Outlet 617-A (Dimensions in mm)

the relatively fast gutter flow velocities limited the amount of water entering the opening in the curb. The outlet discharge increased substantially with an increasing crossfall.

The outlet discharges were compared against those for standard MTC grates DD-713-A and B. On low grades (≤ 0.01 m/m), the outlet capacity was comparable to that of the MTC grate inlets. On steeper grades, the outlet capacity fell rapidly below that of the grate inlets. For the three grades tested, the overall mean outlet capacity amounted to 88 to 95% of that of the MTC grate inlets (see Table 5).

It was also of interest to investigate the effect of the outlet width on its capacity. For this purpose, a series of experiments was conducted using a modified 45° gutter outlet. This modification consisted in doubling the outlet bottom width from 0.44 m to 0.88 m. These experiments were done for only one grade (0.003 m/m) and the results are plotted in Figure 17.

The data in Figure 17 indicate that the outlet capacity increased with the increasing outlet channel width. Such increases were greater for large spreads and crossfalls and their maxima ranged from 19% for the crossfall of 0.02 m/m to 33% for the crossfall of 0.06 m/m. It is expected that even smaller increases would be observed for steeper grades.

3.7.1.1/ 45° Gutter Outlet 617-C – End of Run

The gutter outlet 617-C which is shown in Figure 18 was tested for the same range of parameters as the earlier discussed outlet 617-A. The outlet 617-C performed similarly as the earlier described outlet 617-A, particularly on low grades (0.003 and 0.01 m/m) where both outlets conveyed almost identical discharges (see the data listing in the Appendix). For the steepest grade of 0.04 m/m, the outlet 617-C provided for a better interception of the gutter flow and its deflection into the outlet opening and, consequently, produced discharges almost 40% higher than those for the outlet 617-A.

It was observed that both 45° gutter outlets 617-A and 617-C are susceptible to the overtopping of the outlet curb on the downstream side. Such overtopping was more frequent for large grades, crossfalls and spreads. The incidence of curb overtopping could be reduced by increasing the downstream curb height but such an arrangement may be hazardous to the traffic.

The terms of reference called for the extrapolation of the data obtained for the outlet 617-A to the outlet 617-B. The main difference between both outlets consists in slightly different cross-sectional areas. Although the bottom width of both outlets is the same (0.44 m), the curbs which form outlet sidewalls differ. The outlet 617-A uses the curb A and outlet 617-B uses curb B. Thus for the maximum flow depth of 0.125 m, the cross-sectional area for the outlet 617-A is about 43% larger than that of the outlet 617-B. Such an increase was considered significant and was accounted for in the data extrapolations which were based on the increases of outlet capacity with the increasing outlet cross-section (Figure 17) and the ratio of cross sectional areas for both outlets. The data extrapolated for the outlet 617-B are listed in the Appendix. On the average, the extrapolated capacity of the outlet 617-B is about 9% greater than that of outlet 617-A.

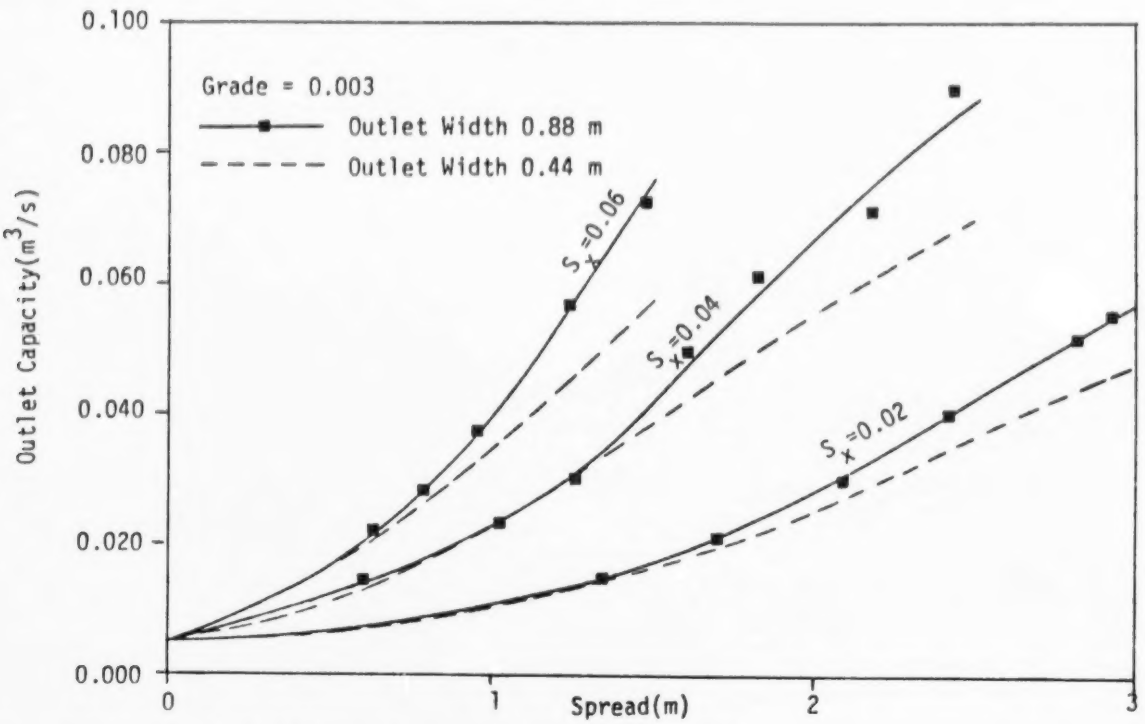


Figure 17/ Effects of Outlet Width on its Capacity (45° Outlet 617-A)

3.7.2/ Gutter Outlets in Sag

The terms of reference called for the testing of the 90° outlet 616-A (see Figure 19) in a sag and extrapolation of the test data to the outlets 616-B and 616-D which have the same alignment and bottom width, but different curbs and cross-sectional areas. The letters in the outlet designations refer to the type of curb used.

The discharges observed for the 90° outlet, with curb A (616-A), in a sag are plotted in Figure 20 and listed in the Appendix. The outlet discharge curve somewhat differs from the corresponding curves for grate inlets in a sag. The increase in the outlet discharge with the increasing depth of ponding is gradual and, generally, the outlet discharges are lower than those for conventional MTC grates.

To extrapolate the data from the outlet 616-A to the other two outlets, the extrapolated flows were taken as linearly proportional to the flow cross-sectional areas. The extrapolated flow curves for the outlets 616-B and 616-D are listed in the Appendix.

Comparisons of various outlet capacities in sag indicate that the outlet 616-D (i.e., a 90° outlet with curb D) has the greatest flow cross-sectional areas and discharges for depths greater than 0.04 m. The outlet 616-B has the smallest flow area and extrapolated discharges. Without overtopping the curb, the maximum discharges of the 90° outlets in sag are fairly moderate and range from 0.043 to 0.055 m^3/s.

In summary, gutter outlets are fairly effective in removing water from the roadway. In grade installations studied, the outlets conveyed about 90% of the grate inlet discharge. An increase in the outlet width brought about only a moderate increase in the outlet capacity. In sags, the gutter outlets studied conveyed only moderate discharges of about 0.050 m^3/s without overtopping the side curbs.

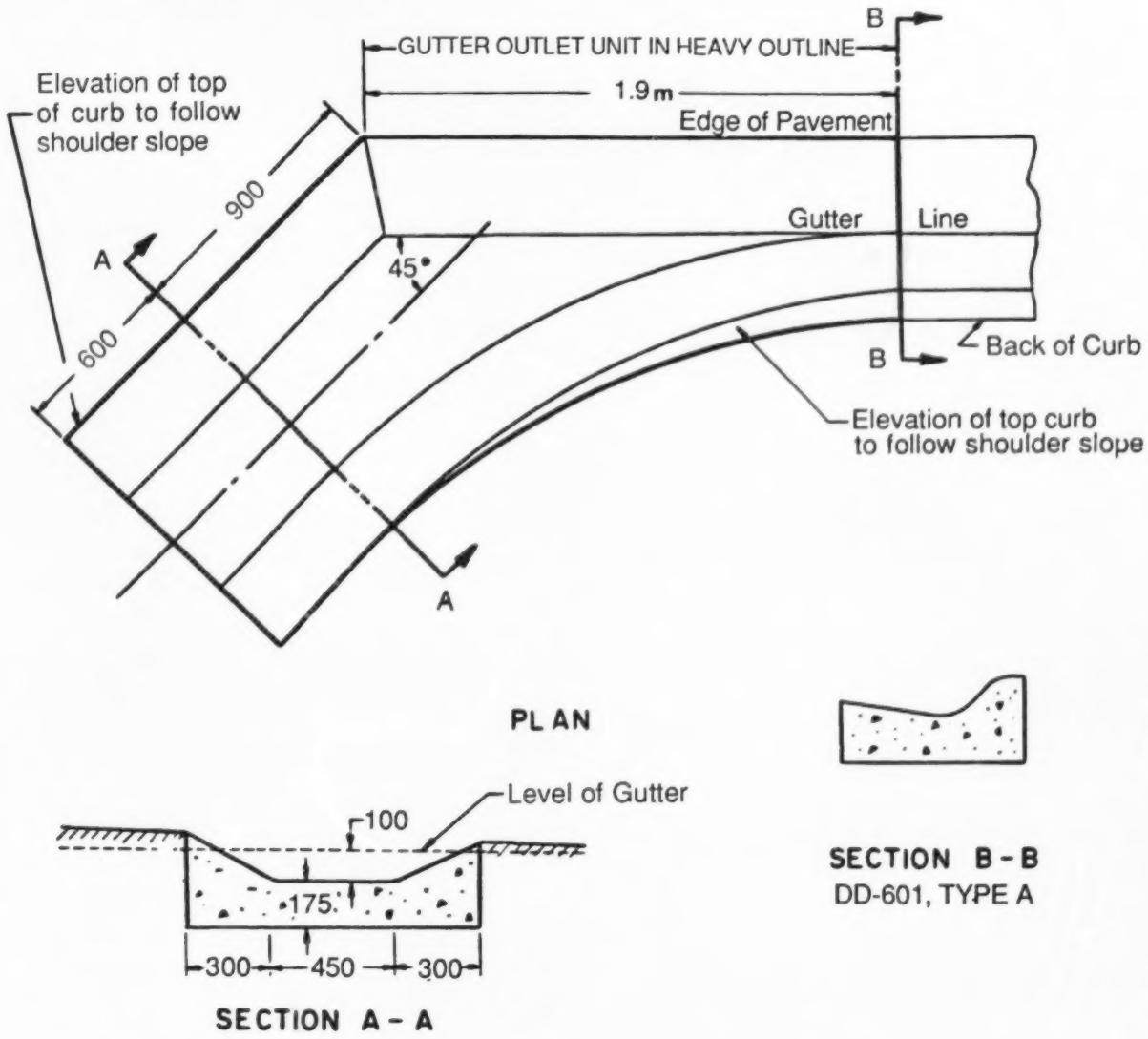


Figure 18/ Gutter Outlet 617-C — End of Run (Dimensions in mm)

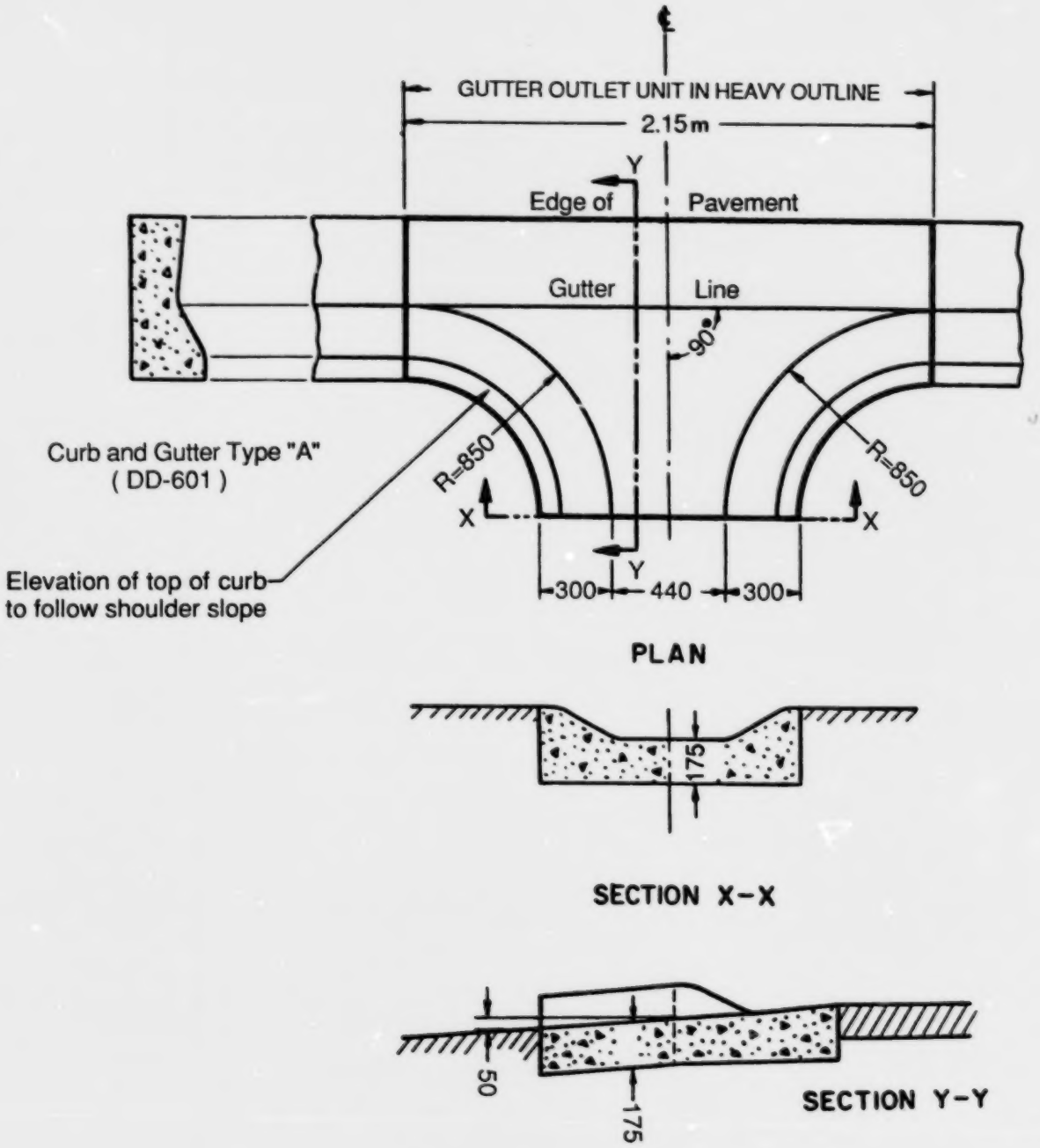


Figure 19/ 90° Gutter Outlet in Sag (Dimensions in mm)

3.8/ Catch Basin Setbacks

Catch basin setbacks are special drainage structures which provide for an expansion of the gutter width and these expanded sections are then used for the placement of drainage inlets. Such increases in the gutter width, which range from 1.0 to 1.3 m, are accomplished in short and long setbacks over the length of 1.68 and 3.81 m, respectively.

The terms of reference called for the testing of three setbacks – the short setback SD-6-387, the long setback SD-6-382 and a new teardrop design to be developed in this study. The setbacks tested are shown in Figures 21 to 23. The scope of the test program is summarized below.

Structures Tested:
- Catch basin setbacks SD-6-382 (long type),
- SD-6-387 (short type), and
- a new teardrop design (combines the upstream section of SD-6-382 and the downstream section of SD-6-387)

Grate Inlet:	DD-705 in single and twin installations
Curb and Gutter:	DD-601, type A
Grades:	0.003 to 0.04 m/m
Crossfalls:	0.02 to 0.04 m/m
Spreads:	0.5 to 3.0 m

3.8.1/ Setbacks on Grade

In the first stage of analysis, capacities of the three setbacks were compared. It was noted that the short setback (SD-6-387) had the lowest discharges in both single and twin installations. The discharges for the long (SD-6-382) and teardrop setbacks were practically identical (within 2%) and exceeded those of the short setback by about 14%. Subsequently, the data for the long and teardrop setbacks were grouped together and used to produce joint capacity curves for both types of setbacks.

The setback capacity curves are plotted in Figures 24 and 25. Compared to the capacity curves of standard grate inlets in conventional installations, the decrease in the setback inlet capacity occurs on lower grades and is sharper. The numerical values corresponding to Figures 24 and 25 are listed in the Appendix.

The discharge data for twin installations are listed in the Appendix. Again, the long and teardrop setbacks produced comparable capacities which were somewhat greater than those corresponding to the short setback. The comparison of overall capacities, defined as the sum of all discharges for all spreads, grades and crossfalls tested, indicated that twin setbacks have capacities about 27% greater than single setbacks.

In both single and twin installations some overflow of water from the setback was observed in the downstream section.

3.8.2/ Setbacks in Sag

The three setbacks studied were also tested in a sag. The results of these experiments are shown in Figures 26 and 27 for single and twin installations, respectively. The discussion of results follows.

3.8.2.1/ Single Grate Installations

As evident from Figure 26, the performance of setbacks in sag differed. Such differences were primarily caused by the presence of strong vortices which were formed in the vicinity of the grate inlet and reduced substantially the inlet discharge. The formation of such vortices was affected by the setback geometry.

The capacity curves in Figure 26 indicate three regions of set-back inlet operation – the region with relatively smooth flow conditions (no large-scale vortices), the transition region with swirling of water, and the region with a strong vortex formed over the

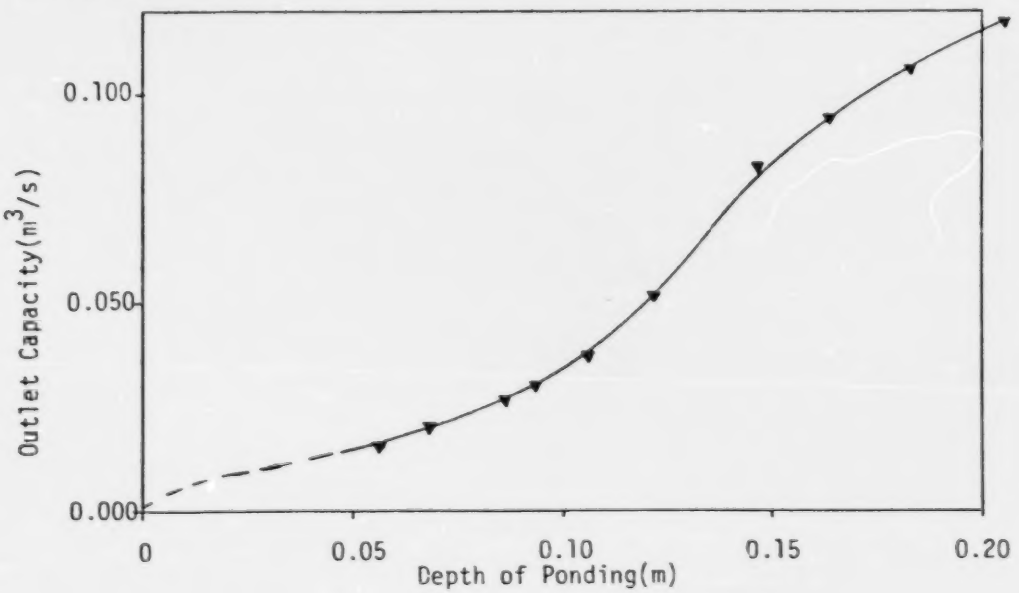
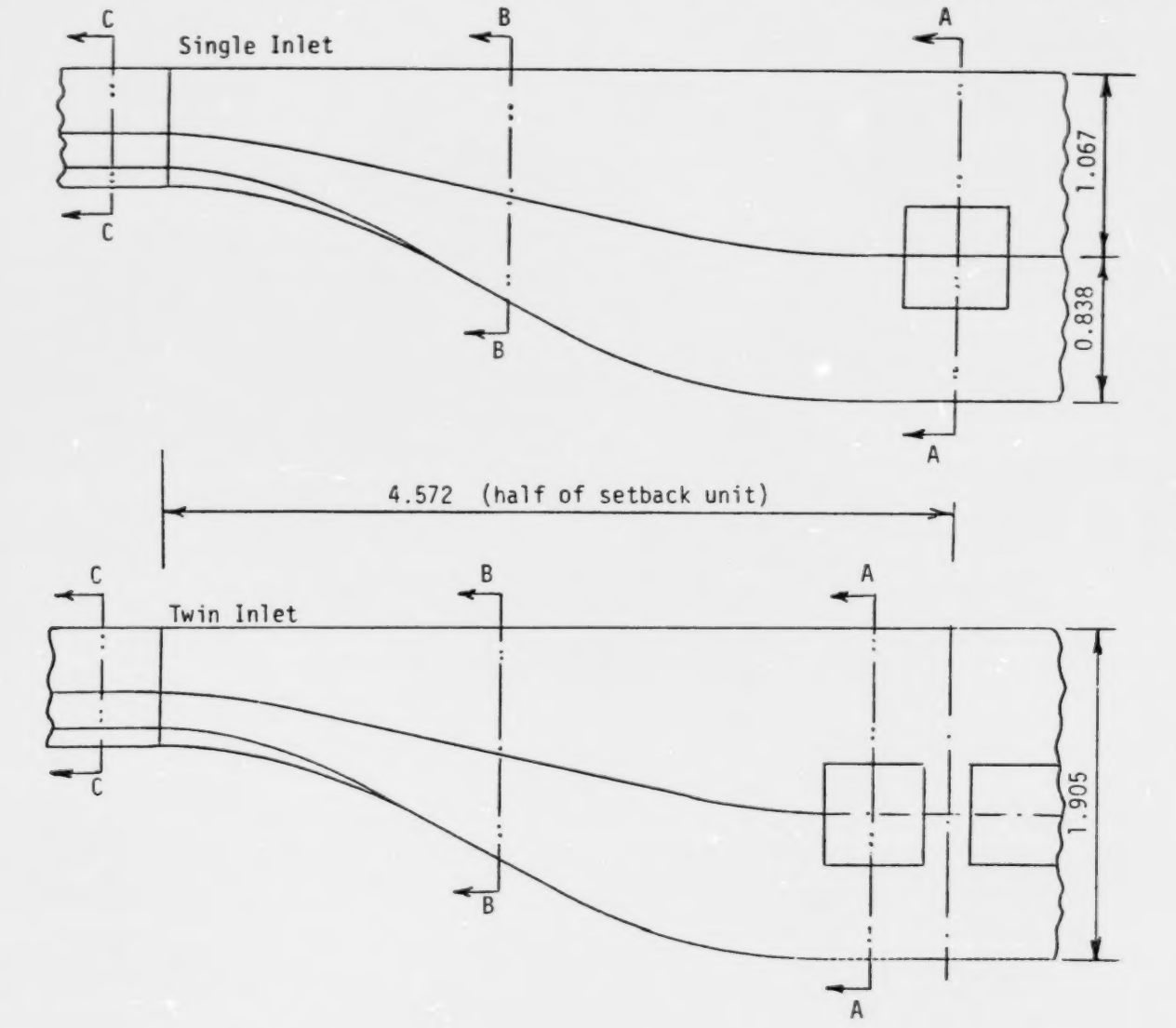


Figure 20/ Discharge Capacity of 90° Outlet (616-A) in Sag

inlet. The boundaries between various regions are not well defined and this introduces some uncertainty into the experimental results.

When examining individual setbacks, differences in their operation and capacities were noticed. The lowest capacities were observed for the short setback. The capacity curve started to fall slightly below the grate inlet curve at the depth of 0.08 m and a sharp bend was noted at the depth of 0.12 m when a strong vortex was formed. For depths greater than 0.20 m, the short setback capacity started to increase significantly. The long setback produced somewhat higher capacities and the transition region appeared to be narrower. The teardrop design retained high capacities for the ponding depths up to 0.15 m, the transition region was observed for depths from 0.15 to 0.20 m and past that limit, the setback inlet capacity started to increase again. The discharge curves in Figure 26



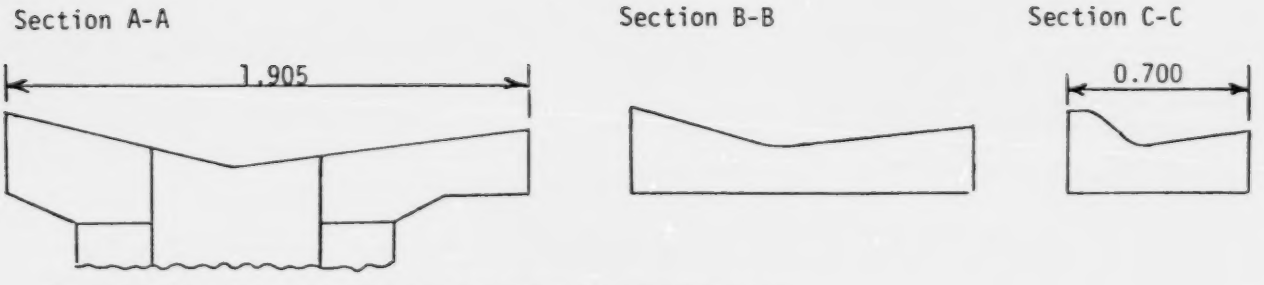


Figure 21/ Long Catch Basin Setback SD-6-382 (Dimensions in Metres)

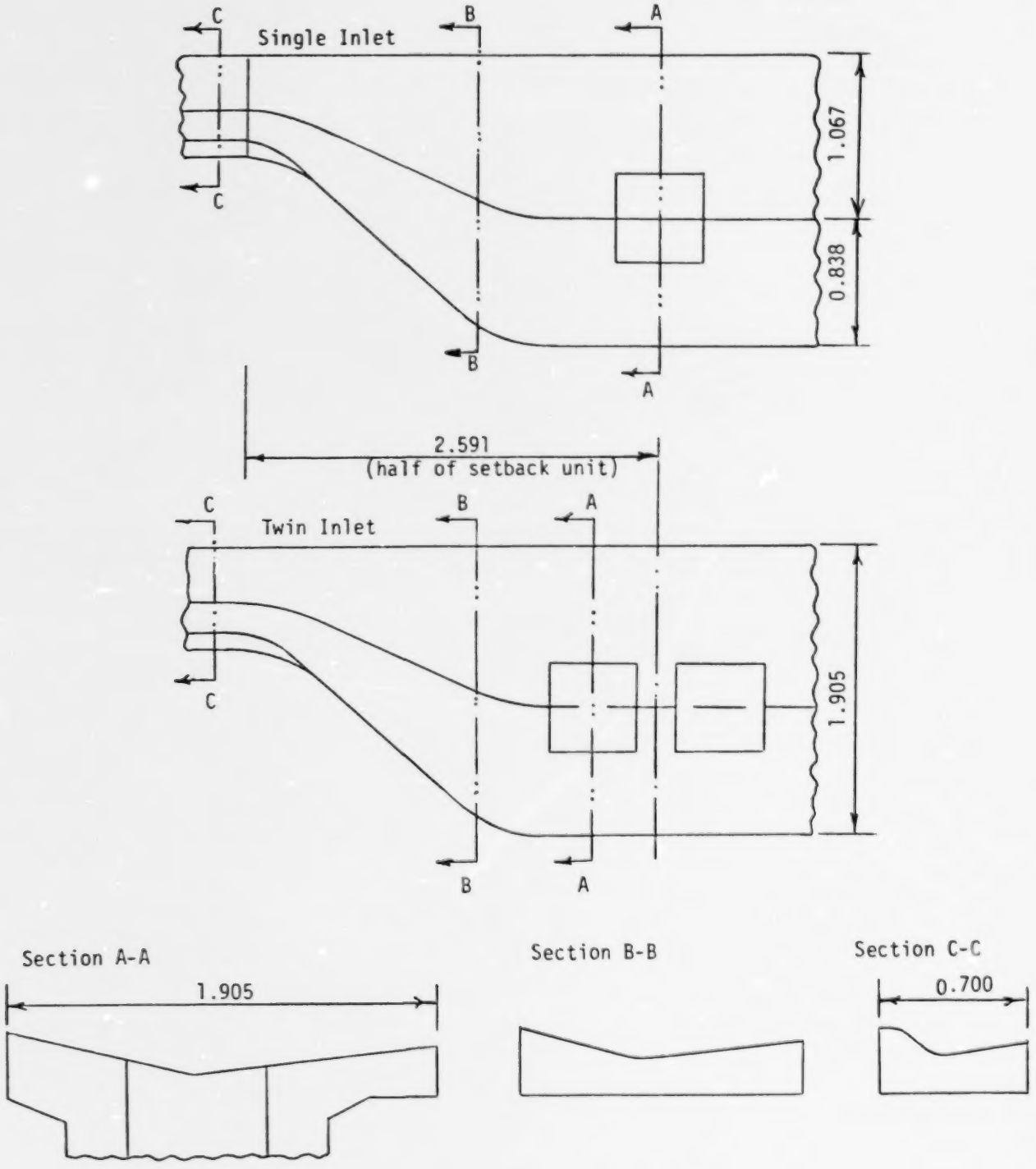
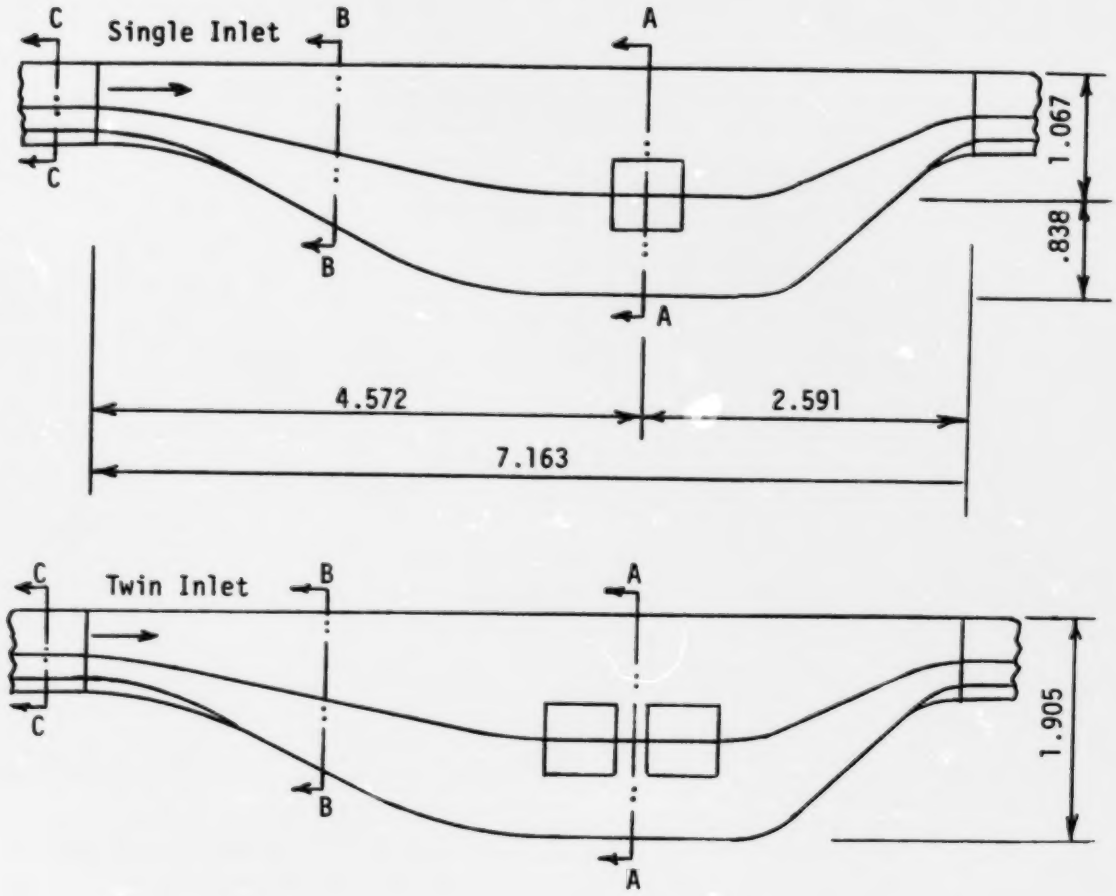


Figure 22/ Short Catch Basin Setback SD-6-387 (Dimensions in Metres)



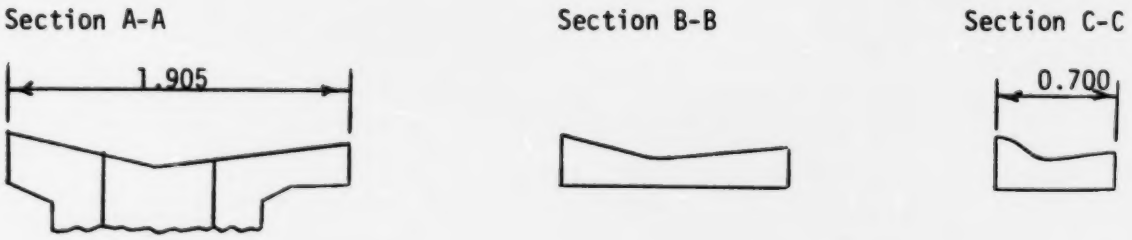


Figure 23/ Teardrop Catch Basin Setback (Dimensions in Metres)

were digitized and the digitized data are presented in the Appendix. When using these data, some caution is in order because of various transients observed in the experimental apparatus and their possible influence on results.

A similar approach was taken in investigations of setbacks with twin inlets of which capacities are shown in Figure 27. As for single inlets, the twin teardrop setback produced the highest capacity, followed by the long and short setbacks. For higher depths of ponding (greater than 0.18 m), all three designs produced almost identical results. Considering the high discharges through the facility, difficulties with controlling experimental conditions and the resulting uncertainty in the data, the curves in Figure 27 were not digitized and should be used only for guidance in the design.

In summary, the newly proposed teardrop setback, which combines the upstream section of the long setback with the downstream section of the short setback performed best on grade as well as in a sag among the designs tested. By twinning the inlet, an average increase in the capacity of 27% was obtained. In sag installations, all setbacks were susceptible to the formation of vortices over the inlet and this greatly reduced their capacity.

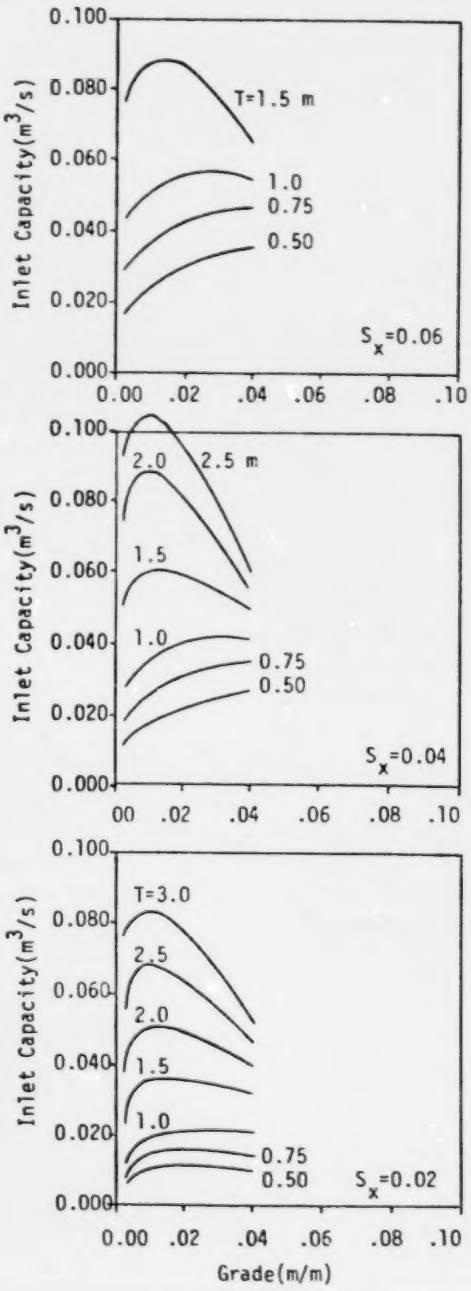


Figure 24/ Inlet Capacity in Long and Teardrop Setbacks (Grade DD-705)

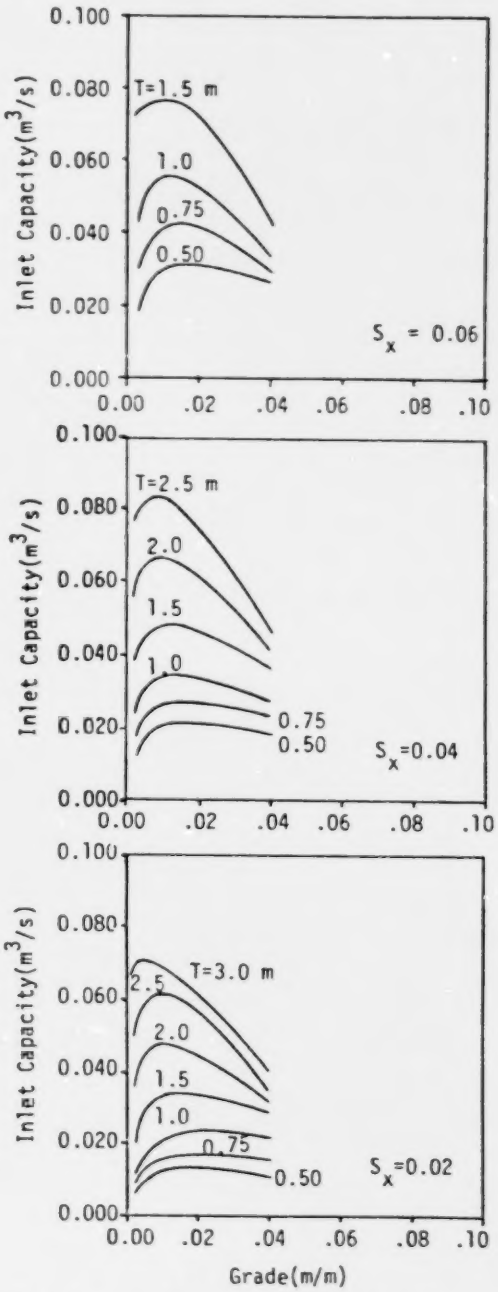


Figure 25/ Inlet Capacity in Short Setback (Grade DD-705)

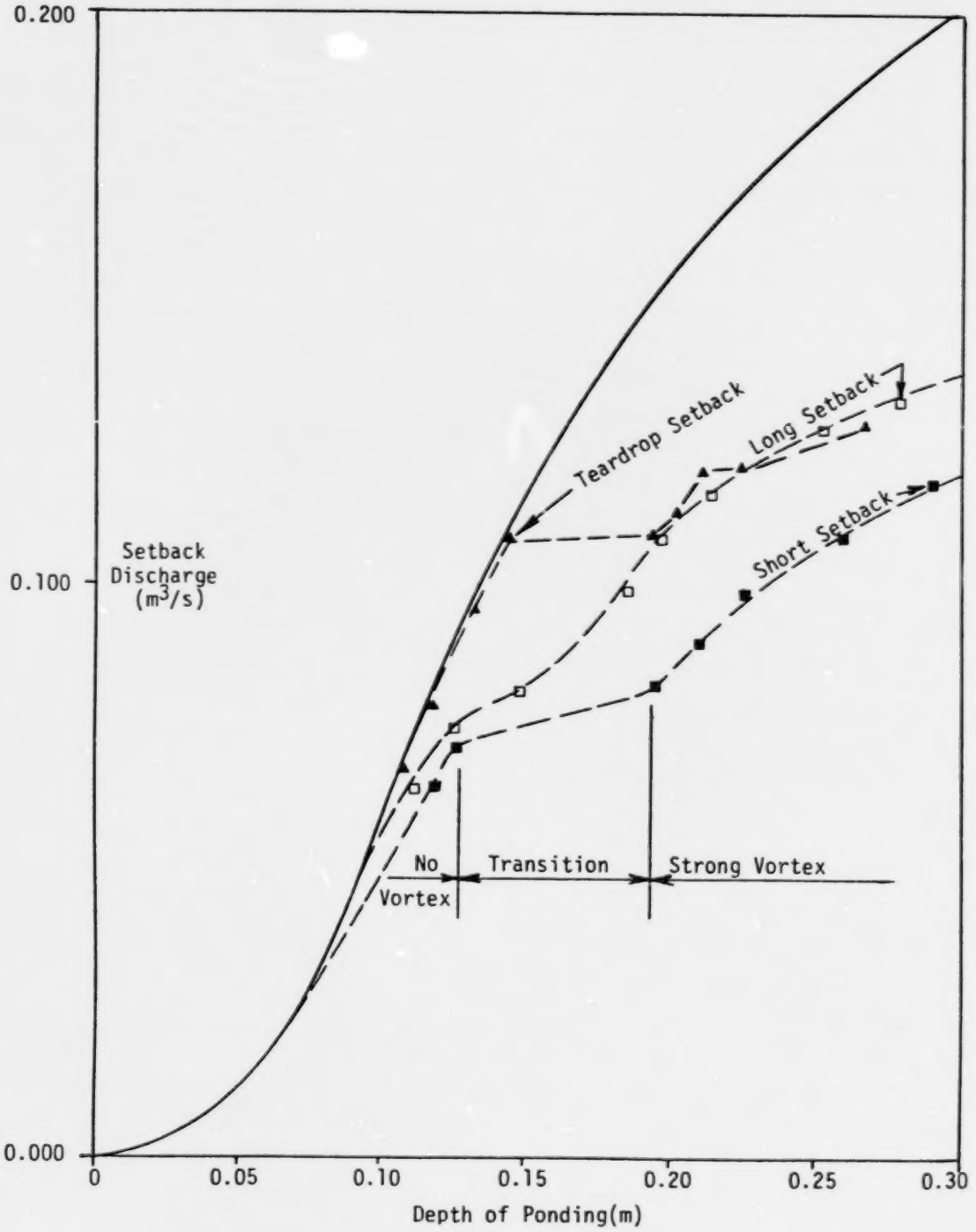


Figure 26/ Capacities of Setbacks With Single Grate DD-705 in Sag

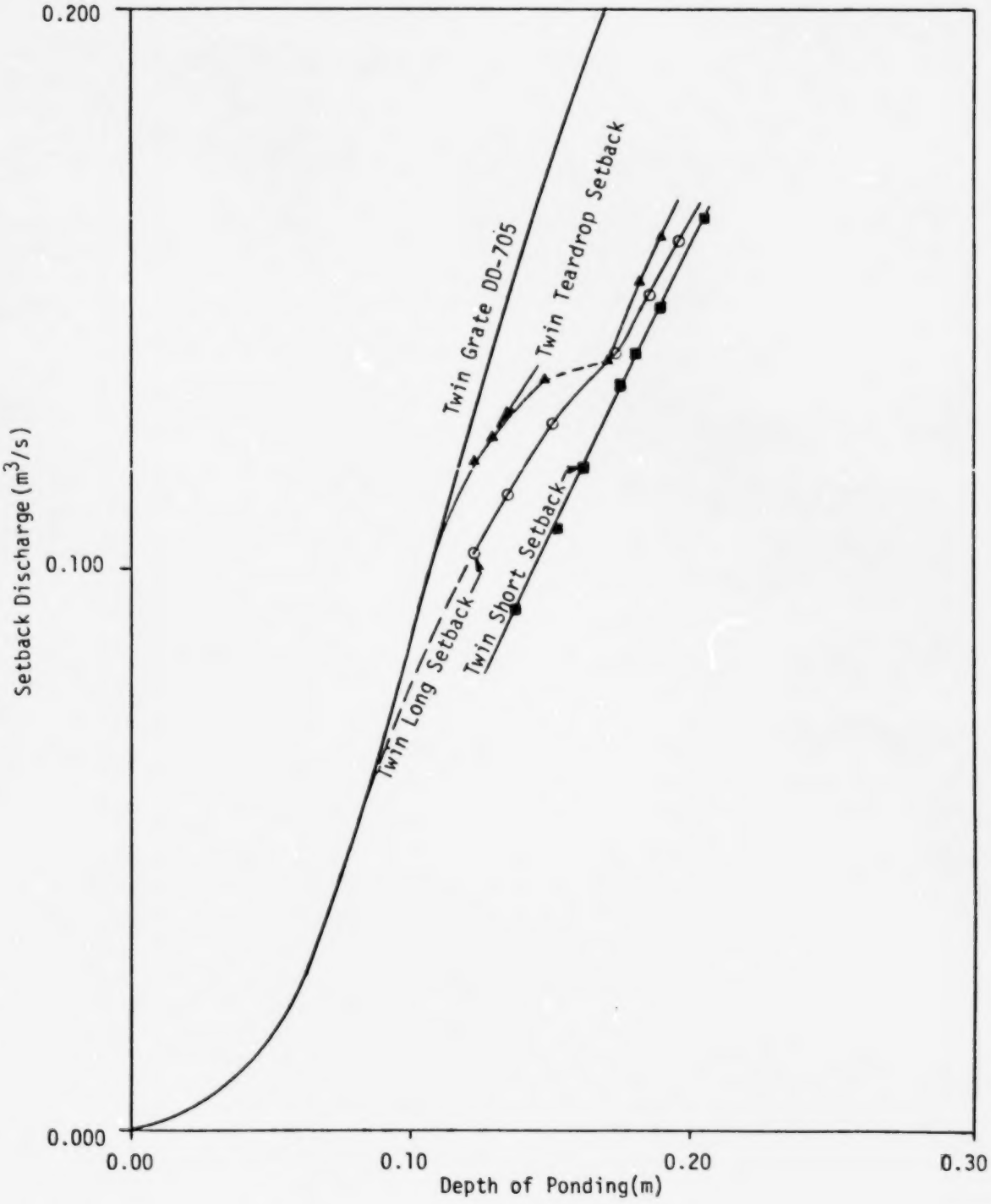


Figure 27/ Capacities of Setbacks With Twin Grates DD-705 in Sag

4/ Summary of Findings

The principal findings of the study of road drainage structures are summarized in this section. These findings were derived from the laboratory investigations in which drainage inlets were considered as part of the gutter-inlet system and for a quasi-uniform flow upstream of the inlet.

4.1/ Depressed Inlets

The installation of inlets in a 60 mm depression resulted in increased inlet capacities on grade as well as in a sag. On grade, the average increases resulting from single and twin inlet installations in depressions were 20% and 27%, respectively. The lowest increases were found for low grades and small spreads where the nondepressed inlets operate rather efficiently. The highest capacity increases were found for large spreads and crossfalls.

Even greater increases in capacity were found in sag installations. The benefits achieved by installing inlets in depressions have to be weighed against their obvious disadvantages — the depressions may disrupt the flow of traffic, require higher maintenance, and accumulate debris which may lead to the inlet clogging. Field evaluations are recommended before implementation of depressed inlets in road drainage practice.

4.2/ Inlet Capacities for Small and Large Spreads

The small spread experiments were carried out to determine the maximum inlet discharges with full interception (no carryover). Such discharges varied with the grade and the grate type. For grades greater than 0.01 m/m, the fully intercepted maximum discharge rapidly decreased from 0.017 to 0.020 m^3/s on a grade of 0.01 m/m, to 0.003 - 0.006 m^3/s on a grade of 0.06 m/m.

Inlet capacities for large spreads were determined from experimental data collected for the corresponding large depths of flow. These experiments were done in a hydraulic flume of limited width (1 m) and their results reflect somewhat different conditions than those produced on the experimental roadway. For the grate inlet tested, it was possible to extrapolate the earlier data on the basis of the flow depth and then to determine the corresponding spreads of the flow.

4.3/ Ductile Iron Grate

The ductile iron grate recently developed by CANRON Inc. has several desirable features, such as a low weight, high grate porosity and relatively good flow capacities. The mean capacity of the ductile iron grate was estimated as about 86% of the conventional MTC designs. Further improvements in the ductile iron grate capacity could be achieved by incorporating a slot next to the curb in this design.

4.4/ Combination Inlets

Two combination inlets obtained by adding a separate curb part to conventional grate inlets were tested on grade and in a sag.

It was noted that, for low crossfalls (0.02 m/m), the combination inlet capacity barely exceeded that of the corresponding grate inlets. The best use of combination inlets appears to be in sag installations where the combination inlet capacity significantly exceeds the grate inlet capacity, particularly for larger depths of ponding. Furthermore, the curb opening provides a relief should the grate become clogged. This safety feature is very important in sag installations where all drainage water must be removed through sewer inlets.

4.5/ Round Frame Grate

The new round frame grate was found clearly superior to the earlier studied design. The arrangement of the grate bars (diagonal, pointing towards the curb in the flow direction) and the absence of the central supporting crossbar enhance the hydraulic performance of this new design. The round frame grate had mean capacities amounting to about 85 to 95% of those of the conventional MTC grates. Further improvement could be achieved by incorporating a slot, next to the curb, in this design.

4.6/ Ditch Inlets with Grate Slope of 6:1

Ditch inlets with longitudinal bars or crossbars, spaced at 127 mm, were tested in installations with a grate slope of 6:1. For identical depths of flow, the grates with the flatter slope (6:1) conveyed higher discharges, by up to 33%, than the grates with steeper slopes (1:1 and 2:1). The grates with flatter slopes are somewhat more expensive because of higher material requirements.

4.7/ Gutter Outlets

Gutter outlets on grade function similarly as grate inlets. Their capacity first increases for low grades and then decreases rather rapidly for high grades. The effect of the outlet width on its capacity was rather minor. Consequently, it was feasible to extrapolate the data from the outlet 617-A (curb A) to the outlet 617-B which incorporates the curb B. It was noted

that for high grades and flow spreads, some water would run over the downstream curb of the outlet structure.

For sag conditions, only one design was tested (616-A; 90° outlet, curb A) and the data were extrapolated to similar designs, with curbs B and D,on the basis of flow cross-sectional areas. The maximum discharges observed in sag were rather low — about 0.055 m^3/s.

4.8/ Catch Basin Setbacks

Three setbacks were tested:

- SD-6-382 (the long type),
- SD-6-387 (the short type), and
- a new teardrop design which was obtained by combining the long upstream and short downstream sections.

On grade, the long and teardrop setbacks with a single inlet produced about identical capacities which were about 14% higher than those of the short setback. Similar findings were obtained for setbacks with twin inlets. In comparison to single inlets, twin inlets in setbacks conveyed about 27% more flow. As in the case of outlets, some overunning of downstream curbs was observed for higher flows.

In setback installations in a sag, the inlet operation was adversely affected by the formation of vortices. Consequently, the inlet capacities in setbacks were lower than those of inlets in standard gutters. The short setback was particularly susceptible to vortex formation.

The new teardrop design performed quite well and should be considered for implementation in drainage practice.

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[1] "Curb Inlet Catch Basin Drawing S-200-M," The City of Burlington, Burlington, April 1983.

[2] "The Design of Storm Water Inlets," John Hopkins University, Baltimore, June 1956.

[3] Marsalek, J., "Road and Bridge Deck Drainage Systems," RR 228, Ministry of Transportation and Communications, Toronto, November 1982.

[4] Marsalek, J., "Road and Bridge Deck Drainage Systems Study Proposal," National Water Research Institute, Burlington, February 1983 (updated on September 8, 1983).

[5] "Research Needs Statement – Project 22314," Ministry of Transportation and Communications, Toronto, January 1983.

[6] "Specification Drawings for Gutter Outlets and Catch Basin Setbacks," Ministry of Transportation and Communications, Toronto, January 1976 to June 1981.

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A1/ Capacities of Depressed Inlet DD-713-A

Grate: DD-713-A Installation: Depressed, 60 mm

Curb and Gutter: B Spread: 0.5 - 3.0 m

Grade: 0.003 - 0.06 Crossfall: 0.02 - 0.06

Source of Data: Interpolations of experimental data

Graphical Presentation: Figure 3

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S (m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0053	.0126	.0168	.0192	.0201	.0202
	0.75	.0085	.0157	.0206	.0242	.0260	.0260
	1.00	.0116	.0193	.0250	.0298	.0322	.0313
	1.50	.0182	.0272	.0340	.0392	.0413	.0418
	2.00	.0278	.0397	.0468	.0513	.0532	.0507
	2.50	.0403	.0520	.0586	.0623	.0640	.0612
	3.00	.0480	.0631	.0710	.0750	.0760	.0730
0.04	0.50	.0091	.0191	.0251	.0287	.0305	.0331
	0.75	.0151	.0252	.0322	.0373	.0407	.0462
	1.00	.0222	.0330	.0413	.0470	.0521	.0575
	1.50	.0388	.0515	.0594	.0648	.0696	.0753
	2.00	.0552	.0690	.0767	.0817	.0853	.0903
	2.50	.0691	.0840	.0922	.0960	.0990	.1021
0.06	0.50	.0149	.0257	.0341	.0383	.0412	.0446
	0.75	.0250	.0386	.0484	.0545	.0590	.0651
	1.00	.0367	.0480	.0594	.0678	.0752	.0850
	1.50	.0611	.0831	.0962	.1027	.1063	.1085

A2/ Capacities of Twin Depressed Inlet DD-713-A

Grate: Twin DD-713-A Installation: Depressed, 60 mm

Curb and Gutter: B Spread: 0.5 - 3.0 m

Grade: 0.003 - 0.06 Crossfall: 0.02 - 0.06

Source of Data: Interpolations of experimental data

Graphical Presentation: Figure 4

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S (m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0071	.0122	.0180	.0227	.0249	.0247
	0.75	.0090	.0160	.0243	.0303	.0330	.0287
	1.00	.0122	.0207	.0300	.0370	.0394	.0340
	1.50	.0194	.0316	.0412	.0466	.0486	.0463
	2.00	.0312	.0456	.0553	.0602	.0627	.0643
	2.50	.0431	.0607	.0713	.0767	.0798	.0837
	3.00	.0592	.0722	.0822	.0901	.0960	.1043
0.04	0.50	.0110	.0199	.0276	.0323	.0364	.0417
	0.75	.0158	.0263	.0367	.0440	.0503	.0600
	1.00	.0230	.0332	.0468	.0573	.0675	.0848
	1.50	.0434	.0576	.0765	.0897	.0988	.1072
	2.00	.0656	.0923	.1114	.1200	.1244	.1263
	2.50	.0890	.1150	.1320	.1400	.1440	.1475
0.06	0.50	.0150	.0266	.0359	.0421	.0472	.0559
	0.75	.0247	.0404	.0544	.0653	.0750	.0881
	1.00	.0382	.0562	.0772	.0922	.1031	.1180
	1.50	.0726	.1000	.1223	.1374	.1450	.1501

A3/ Capacities of Single and Twin Depressed Inlets DD-713-A

Grate: DD-713-A

Installation: Depressed, in Sag

Curb and Gutter: B

Crossfall: 0.02

Source of Data: Modified Data from [3]

Graphical Presentation: Figure 5

Depth of Ponding (m)	Depressed Grate DD-713-A	Twin Depressed DD-713-A
0.00	0.0171	0.0256
0.02	0.0347	0.0530
0.04	0.0600	0.0908
0.06	0.0853	0.1256
0.08	0.1082	0.1548
0.10	0.1278	0.1820
0.12	0.1441	0.2111
0.14	0.1569	0.2440
0.16	0.1671	0.2749
0.18	0.1768	0.3067
0.20	0.1860	0.3395
0.22	0.1946	0.3727
0.24	0.2027	0.4054

Note: The depth of ponding is measured in the gutter outside of the depression. The depth of 0.00 m corresponds to the depth of 0.06 m in the depression. Because of close agreement between the experimental data and the earlier produced sag capacity curves [3], the above data were obtained by transformation of the original sag curves. In this transformation, the new depth, outside of the depression, equals the original depth minus the depression (0.06 m). For low depths of ponding, it is assumed that the inlet discharge can be supplied by gutter flow.

A4/ Maximum Inlet Discharges with Full Interception (Crossfall $S_x = 0.06$)

Grate	Curb & Gutter	Maximum Inlet Discharge With Full Interception (m^3/s)							
		Grade (m/m)							
		0.003	0.01	0.02	0.03	0.04	0.06	0.08	0.10
DD-713-A	A,B	0.0161	0.0197	0.0144	0.0900	0.0066	0.0039	0.0029	0.002
DD-713-B	A,B	0.0140	0.0163	0.0085	0.0062	0.0048	0.0028	0.0021	0.001
DD-705	D	0.0089	0.0159	0.0110	0.0083	0.0069	0.0053	0.0043	0.003

A5/ Capacities of Grate DD-713-A (Curb and Gutter Type B) Extrapolated for Large Depths

S_x	Spread (m)	Depth (m)	Inlet Capacity (m^3/s)			
			Grade (m/m)			
			.003	.01	.02	.03
.02	4.0	.13	.0592	.0810	.0830	.0850
	5.0	.15	.0730	.0940	.0970	.0970
	3.0	.17	.0820	.0960	.1000	.1020
.04	4.0	.21	.1060	.1170	.1190	.1190
	5.0	.25	.1210	.1280	.1320	.1290
	2.0	.17	.0800	.0950	.1000	.1020
.06	2.5	.20	.0985	.1120	.1180	.1160
	3.0	.23	.1140	.1240	.1300	.1270
	1.5	.17	.0720	.0830	.0860	.0850
.08	2.0	.21	.0980	.1090	.1100	.1040
	2.5	.25	.1210	.1260	.1270	.1200

A6/ Capacities of Ductile Iron Grate

Grate: Canron Ductile Iron

Installation: Non-depressed

Curb and Gutter: B

Spread: 0.0 - 3.0 m

Grade: 0.003 - 0.06

Crossfall: 0.02 - 0.06

Source of Data: Interpolations of experimental data

Graphical Presentation: Figure 8

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0027	.0065	.0096	.0107	.0107	.0075
	0.75	.0043	.0090	.0131	.0145	.0142	.0106
	1.00	.0062	.0123	.0170	.0184	.0177	.0136
	1.50	.0144	.0197	.0247	.0263	.0251	.0196
	2.00	.0265	.0312	.0348	.0350	.0328	.0265
	2.50	.0441	.0460	.0454	.0438	.0412	.0340
	3.00	.0658	.0654	.0623	.0581	.0533	.0415
0.04	0.50	.0062	.0103	.0137	.0160	.0166	.0161
	0.75	.0100	.0145	.0183	.0207	.0214	.0212
	1.00	.0151	.0197	.0238	.0260	.0267	.0267
	1.50	.0300	.0336	.0369	.0388	.0391	.0384
	2.00	.0491	.0525	.0550	.0510	.0550	.0510
	2.50	.0732	.0756	.0752	.0742	.0717	.0665
0.06	0.50	.0120	.0182	.0217	.0243	.0256	.0278
	0.75	.0191	.0240	.0277	.0312	.0330	.0362
	1.00	.0277	.0325	.0360	.0393	.0412	.0440
	1.50	.0472	.0513	.0543	.0571	.0590	.0611

A7/ Capacities of Combination Inlets in Sag

Grate: Combination Inlet with Grates DD-713-A and B Installation: In Sag

Crossfall: 0.02 Curb and Gutter: B

Source of Data: Interpolations of experimental data

Graphical Presentation: Figure 11

Depth of Ponding (m)	Inlet Discharge (m^3/s)
0.00	0.0000
0.02	0.0024
0.04	0.0077
0.06	0.0182
0.08	0.0369
0.10	0.0640
0.12	0.0968
0.14	0.1302
0.16	0.1585
0.18	0.1833
0.20	0.2016

A8/ Capacities of Round Frame Grate in Sag

Grate: Round Frame Grate Installation: In Sag

Curb and Gutter: B

Source of Data: Interpolations and Extrapolations of Experimental Data

Graphical Presentation: Figure 13

Depth of Ponding (m)	Inlet Discharge (m^3/s)
0.00	0.0000
0.02	0.0019
0.04	0.0067
0.06	0.0153
0.08	0.0273
0.10	0.0407
0.12	0.0578
0.14	0.0778
0.16	0.0962*
0.18	0.1131*
0.20	0.1283*
0.25	0.1562*
0.30	0.1741*

* *Extrapolated Data*

A9/ Ditch Inlet Capacity — Designs B and D

Grate Width: 1.00 m

Inlet type: B and D

Grate Slope: 6:1

Graphical Presentation: Figure 15

Flow Depth (m)	Ditch Inlet Discharge (m^3/s)	
	B	D
0.00	0.0000	0.0000
0.02	0.0109	0.0149
0.04	0.0258	0.0337
0.06	0.0457	0.0526
0.08	0.0716	0.0793
0.10	0.1074	0.1081
0.12	0.1442	0.1339
0.14	0.1819	0.1696
0.16	0.2217	0.2023
0.18	0.2625	0.2400
0.20	0.3122	0.2866
0.25	0.4345	0.3917
0.30	0.5577*	0.5187
0.35	0.6930*	0.6446*
0.40	0.8471*	0.8132*
0.45	1.0012*	0.9917*
0.50	1.1781*	1.2200*

* *Extrapolated data*

A10/ Capacities of Gutter Outlet 617-A

Structure: 45° Outlet (617-A)

Grate:

Curb and Gutter: A

Source of Data: Interpolations of experimental data

Spread: 0.5 - 3.0 m

Crossfall: 0.02 - 0.06

Grade: 0.003 - 0.04

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0067	.0103			.0138	
	0.75	.0085	.0130			.0170	
	1.00	.0108	.0163			.0207	
	1.50	.0167	.0240			.0285	
	2.00	.0253	.0320			.0344	
	2.50	.0374	.0397			.0390	
	3.00	.0485	.0456			.0410	
0.04	0.50	.0110	.0152			.0145	
	0.75	.0157	.0213			.0205	
	1.00	.0220	.0287			.0277	
	1.50	.0393	.0410			.0457	
0.06	0.50	.0168	.0243			.0245	
	0.75	.0247	.0330			.0300	
	1.00	.0345	.0405			.0393	

A11/ Extrapolated Capacities of Gutter Outlet 617-B

Structure: 45° Outlet (617-B) Spread: 0.5 - 3.0 m

Curb and Gutter: B Crossfall: 0.02 - 0.06

Grade: 0.003 - 0.04

Source of Data: Interpolations of experimental data

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0069	.0106			.0142	
	0.75	.0090	.0137			.0180	
	1.00	.0114	.0172			.0219	
	1.50	.0174	.0251			.0298	
	2.00	.0276	.0349			.0375	
	2.50	.0420	.0446			.0438	
	3.00	.0568	.0534			.0480	
0.04	0.50	.0120	.0166			.0159	
	0.75	.0165	.0224			.0215	
	1.00	.0227	.0296			.0285	
	1.50	.0421	.0439			.0489	
0.06	0.50	.0172	.0248			.0250	
	0.75	.0264	.0352			.0320	
	1.00	.0391	.0459			.0445	

A12/ Capacities of Gutter Outlet 617-C

Structure: Outlet 617-C (End of Run) Spread: 0.5 - 3.0 m

Crossfall: 0.02 - 0.06 Curb and Gutter: A

Grade: 0.003 - 0.04

Source of Data: Interpolations of experimental data

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0070	.0120			.0195	
	0.75	.0090	.0146			.0221	
	1.00	.0115	.0175			.0253	
	1.50	.0177	.0240			.0329	
	2.00	.0257	.0317			.0423	
	2.50	.0349	.0400			.0528	
	3.00	.0451	.0490			.0643	
0.04	0.50	.0126	.0170			.0270	
	0.75	.0174	.0223			.0342	
	1.00	.0227	.0286			.0417	
	1.50	.0356	.0427			.0596	
0.06	0.50	.0190	.0232			.0328	
	0.75	.0278	.0324			.0425	
	1.00	.0374	.0421			.0540	

A13/ Capacities of 90° Outlets (616-A, B, and D) in Sag

Depth of Ponding (m)	Gutter Outlet Discharge		
	616-A[1] (m^3/s)	616-B[2] (m^3/s)	616-D[3] (m^3/s)
0.00	0.0000	0.0000	0.0000
0.01	0.0051	0.0041	0.0044
0.02	0.0095	0.0075	0.0087
0.03	0.0104	0.0081	0.0100
0.04	0.0130	0.0099	0.0131
0.05	0.0147	0.0110	0.0154
0.06	0.0180	0.0132	0.0196
0.07	0.0206	0.0149	0.0232
0.08	0.0250	0.0178	0.0291
0.09	0.0288	0.0202	0.0345
0.10	0.0350	0.0242	0.0432[3]
0.11	0.0412	0.0281	
0.12	0.0490	0.0330	
0.125	0.0549[3]	0.0367	
0.13	0.0604	0.0401	
0.14	0.0725	0.0475	
0.15	0.0845	0.0546[3]	
0.16	0.0910		
0.18	0.1045		
0.20	0.1155		
0.22	0.1230		
0.24	0.1320		
0.25	0.1355		

1 *Observed data; for depths greater than 0.125 m (the height of the Curb A), the outlet channel was extended by vertical walls 1.04 m apart.*

2 *All data extrapolated from outlet 616-A. The extrapolated flows are linearly proportional to the flow cross-sectional areas.*

3 *Curb - full discharge.*

A14/ Capacities of Catch Basin Setback SD-6-387

Grate: DD-705

Installation: Short Setback SD-6-387

Curb and Gutter: A

Crossfall: 0.02 - 0.06

Grade: 0.003 - 0.06

Spread: 0 - 3.0 m

Source of Data: Interpolations of experimental data

Graphical Presentation:

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0070	.0129	.0141	.0128	.0110	
	0.75	.0100	.0160	.0172	.0170	.0162	
	1.00	.0112	.0211	.0238	.0240	.0223	
	1.50	.0203	.0343	.0346	.0326	.0293	
	2.00	.0364	.0483	.0454	.0397	.0322	
	2.50	.0507	.0631	.0575	.0483	.0352	
	3.00	.0711	.0702	.0624	.0522	.0411	
0.04	0.50	.0116	.0203	.0210	.0199	.0192	
	0.75	.0177	.0268	.0271	.0260	.0243	
	1.00	.0240	.0351	.0343	.0318	.0282	
	1.50	.0406	.0493	.0471	.0430	.0375	
	2.00	.0580	.0676	.0613	.0532	.0426	
	2.50	.0772	.0851	.0755	.0635	.0488	
0.06	0.50	.0176	.0300	.0320	.0304	.0275	
	0.75	.0296	.0420	.0410	.0363	.0307	
	1.00	.0430	.0552	.0515	.0440	.0347	
	1.50	.0745	.0776	.0716	.0591	.0435	

A15/ Capacities of Catch Basin Setback SD-6-382 and Teardrop Setback

Grate: DD-705

Curb and Gutter: A

Spread: 0 - 3.0 m

Crossfall: 0.02 - 0.06

Installation: Setback, and Long Teardrop

Grade: 0.003 - 0.04

Source of Data: Interpolations of experimental data

Graphical Presentation:

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0062	.0104	.0110	.0107	.0095	
	0.75	.0084	.0150	.0162	.0158	.0141	
	1.00	.0120	.0200	.0216	.0220	.0212	
	1.50	.0230	.0362	.0355	.0347	.0320	
	2.00	.0378	.0514	.0490	.0460	.0405	
	2.50	.0563	.0687	.0641	.0572	.0473	
	3.00	.0780	.0840	.0782	.0683	.0525	
0.04	0.50	.0124	.0162	.0221	.0256	.0280	
	0.75	.0185	.0254	.0319	.0348	.0360	
	1.00	.0280	.0362	.0412	.0432	.0429	
	1.50	.0524	.0616	.0602	.0564	.0512	
	2.00	.0753	.0913	.0827	.0702	.0567	
	2.50	.0950	.1067	.0970	.0806	.0615	
0.06	0.50	.0180	.0242	.0300	.0338	.0350	
	0.75	.0304	.0376	.0438	.0464	.0467	
	1.00	.0437	.0512	.0557	.0567	.0544	
	1.50	.0765	.0883	.0857	.0766	.0653	

A16/ Capacities of Twin Catch Basin Setback SD-6-387

Grate: Twin DD-705

Curb and Gutter: A

Spread: 0.0 - 3.0 m

Crossfall: 0.02 - 0.06

Installation: Short Setback SD-6-387

Grade: 0.003 - 0.04

Source of Data: Interpolations of experimental data

Graphical Presentation:

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0066	.0110	.0130	.0130	.0118	
	0.75	.0091	.0154	.0180	.0186	.0180	
	1.00	.0113	.0202	.0257	.0281	.0282	
	1.50	.0203	.0354	.0422	.0472	.0497	
	2.00	.0365	.0526	.0570	.0588	.0596	
	2.50	.0550	.0740	.0732	.0703	.0660	
	3.00	.0762	.0864	.0841	.0777	.0695	
0.04	0.50	.0093	.0211	.0252	.0260	.0260	
	0.75	.0140	.0280	.0329	.0354	.0361	
	1.00	.0222	.0362	.0412	.0441	.0442	
	1.50	.0426	.0600	.0626	.0625	.0587	
	2.00	.0680	.0844	.0831	.0806	.0740	
	2.50	.0964	.1090	.1042	.0957	.0816	
0.06	0.50	.0160	.0322	.0380	.0412	.0424	
	0.75	.0297	.0432	.0483	.0507	.0513	
	1.00	.0471	.0647	.0668	.0653	.0617	
	1.50	.0910	.1042	.0977	.0880	.0732	

A17/ Capacities of Twin Catch Basin Setback SD-6-382 and Teardrop Setback

Grate: Twin DD-705

Curb and Gutter: A

Spread: 0.0 - 3.0 m

Crossfall: 0.02 - 0.04

Installation: Long Setback, Teardrop Setback

Grade: 0.003 - 0.04

Source of Data: Interpolations of experimental data

Graphical Presentation:

Crossfall S_x (m/m)	Spread T(m)	Grate Inlet Capacity (m^3/s)					
		Grade S(m/m)					
		0.003	0.01	0.02	0.03	0.04	0.06
0.02	0.50	.0070	.0088	.0094	.0081	.0066	
	0.75	.0097	.0123	.0152	.0157	.0152	
	1.00	.0136	.0174	.0230	.0263	.0274	
	1.50	.0253	.0350	.0415	.0442	.0460	
	2.00	.0396	.0590	.0611	.0595	.0580	
	2.50	.0593	.0860	.0836	.0763	.0674	
	3.00	.0820	.1153	.1082	.0950	.0761	
0.04	0.50	.0104	.0161	.0214	.0231	.0257	
	0.75	.0190	.0253	.0340	.0397	.0430	
	1.00	.0291	.0392	.0476	.0521	.0551	
	1.50	.0553	.0800	.0810	.0780	.0743	
	2.00	.0886	.1182	.1120	.1015	.0880	
	2.50	.1310	.1352	.1272	.1164	.1000	
0.06	0.50	.0190	.0242	.0330	.0387	.0432	
	0.75	.0328	.0441	.0526	.0571	.0600	
	1.00	.0490	.0665	.0721	.0747	.0751	
	1.50	.0892	.1192	.1170	.1090	.1000	